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SUMMARY AND INTERPRETATION OF THE HYDROGRAPHIC OBSERVATIONS

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THE SCRIPPS INSTITUTION FOR BIOLOGICAL RESEARCH

OF THE

UNIVERSITY OF CALIFORNIA

1908 TO 1915

BY

GEORGE F. McEWEN
Hydrographer

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CONTENTS

PAGE

Introduction 256
A. The region surveyed 257
1. Number of observations in different portions of the region 257
2. Topography of the ocean bottom 257
B. Horizontal distribution of temperatures and salinities 258
1. Surface isotherms and isohalines in several large areas 258
(*a*) Some general principles underlying oceanic circulation 258
(*b*) Methods employed for determining isotherms and isohalines 259
(*c*) Isotherms 259
(*d*) Isohalines 261
2. Surface and subsurface isotherms and isohalines west of the Coronado Islands 263
(*a*) Isotherms 263
(*b*) Isohalines 264
C. Relation of temperature and salinity to distance from the coast 265
1. Isotherms 265
2. Isohalines 266
D. Periodic variations in temperature and salinity 267
1. Seasonal variations 267
2. Mean annual values 270
3. Diurnal variation 271
E. The thermocline and accompanying salinity distribution 272
F. Certain theoretical implications of the observations 274
G. Literature cited 280

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INTRODUCTION

The biological survey of the waters of the Pacific adjacent to the coast of Southern California, which was begun by the Marine Biological Association of San Diego in 1901, has been carried on by its successor, the Scripps Institution for Biological Research of the University of California, since 1912. The aim has been to obtain as comprehensive an understanding as possible of the life of the sea, and consequently considerable time and energy have been devoted to the investigations of the hydrographic conditions under which marine organisms live. The hydrographic data thus accumulated, together with all the other field data and a full discussion of the methods of collecting, laboratory analysis, accuracy of results, etc., have been published in detail (Michael and McEwen, 1915, 1916).

However, as Thompson (1904–05, p. 171) says: "We want to learn the general or average hydrographical conditions of temperature, salinity, and current at each place and at each depth, and then to learn the changes or fluctuations that these conditions undergo during the year or longer periods." To realize this ideal obviously demands a very large number of observations taken at small intervals of time and space, and involves the application of methods of averaging and interpolating. Moreover, the results of such observations can not be adequately described or understood without a quantitative investigation of their causal relationships. Quantitative investigation brings the facts of observation into closer relationship, as logical consequences of known principles of physics and chemistry, and also indicates the existence of other important and related phenomena, and emphasizes the need of devising means for their direct observation.

To obtain even a reasonable approximation to the complete knowledge of the hydrographic conditions in this region that we desire will require far more numerous and continuous observations than have yet been made. However, it is believed that the data now available warrant a brief account of the average hydrographic conditions and their fluctuations.

A. THE REGION SURVEYED

1. Number of Observations in Different Portions of the Region

Both in hydrographic and biological investigations it is often desirable to divide the area to be explored into sections of convenient size and to deal separately with the observations made in each section. Rectangular sections, having bases equal to five minutes of longitude and altitudes equal to five minutes of latitude, have proved very convenient in our oceanic investigations (Michael and McEwen, 1915, p. 46). Accordingly, each number written below the maps (pls. 1–3) is that of the section, twenty-five square minutes in area counted from the base-line, 114° W, and each number in the column at the left is that of the section north or south, as the case may be, of the other base-line, 32° N. Each of these numbers divided by 12 gives the number of degrees from the corresponding base-line to the center of the section to which it refers. Thus the two numbers corresponding to each section locate its center exactly, and therefore all observations are located to within an error of 2.5. The position of a section is indicated in the text (Michael and McEwen, 1915, p. 46) by a section *number* giving the distance *west* of 114° W, accompanied by a *subscript* giving the distance *north* or an *exponent* giving the distance *south* of 32° N. Thus 40_4 defines the section which is the fortieth west of 114° W and the fourth north of 32° N, while 40^4 defines the section which is the fortieth *west* of 114° W and the fourth *south* of 32° N.

The number of observations, biological as well as hydrographic, made in each section prior to June, 1915, is approximately represented by stippling (pls. 1–3); hence these plates represent graphically the approximate number and distribution of observations throughout the whole area surveyed. Fully half of the observations are hydrographic.

2. Topography of the Ocean Bottom

Since it is desirable at the outset to have a general idea of the region explored, attention is first called to the contour maps (pls. 1–3) of the region which extends from Point Conception, 35° N, to Guadalupe and Cerros islands, 28° N. The contours were determined, for the most part, from soundings entered on the United States Coast and Geodetic Survey charts; but our own soundings (Michael and McEwen,

1915, pp. 127–132) were also used, especially in the region west of Los Coronados (or the Coronado Islands, pl. 4). Here our intensive explorations made possible a more detailed representation of the topography. Though but few soundings have been made more than ten miles off shore, it is improbable that future explorations will necessitate any important alteration of the contours.

The contour maps reveal the presence of numerous submerged valleys and other regions where the depth increases rapidly. In fact, depths exceeding a thousand meters are usually found within fifty miles of the coast, and depths exceeding five hundred meters occur in several regions within five miles of the coast. For a detailed discussion of the submerged valleys and other topographic features of the ocean bottom off California and Mexico, the reader is referred to Davidson (1897).

B. HORIZONTAL DISTRIBUTION OF TEMPERATURES AND SALINITIES

1. Surface Isotherms and Isohalines in Several Large Areas

(*a*) *Some general principles underlying oceanic circulation.*— Samples of ocean water taken at different times from the same position, or from different positions at the same time, usually differ in one or more respects, e.g., in temperature, salinity, gas content, etc. Such differences are of course due to variations in the wind, humidity of the air, solar radiation, etc., and to the flow of the water.

Furthermore, water having certain properties often flows as a current or slow drift into regions where the local conditions tend to produce different properties. For example, water flowing from a region where a certain intensity of solar radiation prevails into one of greater intensity is colder than the neighboring still water. And, in general, the presence at any place of water differing significantly in any property from that corresponding to local conditions indicates a flow of water from a region where different conditions prevail.

Any difference in the properties of the water that changes its density tends to give rise to a convective circulation. If acting alone, this circulation would result in a series of layers of water which, while increasing in density *in situ* with the depth, would not vary in density with respect to horizontal distances. In addition, there is

always the effect due to the much slower processes of conduction and diffusion, both of which tend to produce a state of homogeneity vertically as well as horizontally. While any type of circulation which mixes the water accelerates these equalizing processes, there are many factors, such as variation in solar radiation, condition of the air, etc., that have the opposite effect. Accordingly, the distribution of the various properties of sea-water may be exceedingly complex.

Finally, while the distribution of any one property of ocean water affords indirect information concerning its circulation, the combined evidence from more than one is still more valuable. Moreover, in some cases the distribution of several properties, such as temperature, salinity, and gas content, must be known in order to work out the circulation satisfactorily.

(*b*) *Methods employed in determining isotherms and isohalines.*—To determine the exact distribution of temperatures or salinities in a given area at a given time requires a large number of simultaneous observations well distributed throughout the area. On the basis of these observations lines of equal temperature or salinity can be drawn to represent the distribution at that time. All of our observations were made from one boat, and therefore could not be simultaneous. Moreover, they were not as well distributed as we wished, except in a few portions of the area. Nevertheless, an approximation to the average distribution of temperature and salinity during certain months could be worked out in some cases by averaging and interpolating. This has been done, and after applying a correction for the diurnal variation (see p. 271) the average of the values obtained during the particular month considered was computed for each section and was assumed to correspond to the position of its center. It is well to point out, therefore, that the effect of only those approximately continuous influences having, on the average, a tendency to produce fairly constant types of temperature and salinity distribution during the periods of observation are likely to be revealed by the isotherms or isohalines determined in this way.

(*c*) *Isotherms.*—The southward dip of the isotherms southeast of Santa Catalina Island (pls. 5 and 6) and southeast of San Clemente Island (pls. 7 and 8, figs. 7 and 8) reveals a southward flow of water, since lower temperatures are found in the vicinity of the portions of greatest curvature than either east or west of them. The source of this cold water will be considered later. Furthermore, the southerly drift thus revealed agrees, in general, with the average of direct current

observations made by officers cruising in the Pacific and represented on the U. S. Meteorological Charts of the North Pacific Ocean.

While this is the characteristic direction of surface drift, a local and more restricted northward drift of warm water is also shown near the mainland off Point Loma by plates 7 and 8.

The temperatures near the east coasts of the islands are higher than those farther from their shores, as shown off Catalina by plates 5 and 6 and off Guadalupe and Cerros islands by plate 9. This difference in temperatures would be expected because in a deep region, say exceeding two hundred meters, the heat received by any given layer of water is largely derived from the fraction of the solar radiation directly absorbed by that layer. In a shallow region, however, additional heat is communicated by convection and conduction from the bottom. Thus the heat is concentrated in a smaller volume in shallow than in deep water. Also the convection currents due to these high temperatures tend to produce high temperatures for some distance in all directions from the shallow region.

In contrast to the above results, numerous regions of shallow water off the mainland have lower temperatures than the water in their immediate vicinity. For example, in plate 9 two such regions are shown just south of Cape San Quentin, in one of which values as low as 13° C are found with a progressive increase in all directions, and in the other an area having the low temperature of 15° C is circumscribed by warmer water and the coast. Three other cold areas shown by the same plate are also surrounded by the coast and by warmer water. Plate 6 reveals the same phenomenon near Point Fermin and also north of Point Dume; while in Santa Monica Bay much higher temperatures prevail. Since, as was pointed out above, solar radiation would be expected to produce higher temperatures in areas of shallow water, there must be a flow of water from some colder region wherever the surface temperatures are so low. Evidently a surface flow will not account for these low temperatures, because several of these areas are completely circumscribed by the coast and water of a higher temperature. Upwelling of cold bottom water appears to be the only type of circulation that could produce such a distribution of temperatures.

Furthermore, the contour maps (pls. 1–3) reveal a striking correlation between the location of these areas of cold water and the submerged valleys or other regions in which the depth increases rapidly with increasing distance from the coast. For example, the

cold areas north of Point Dume (pl. 6) are close to two submerged valleys, as shown (pl. 1) by the one hundred and the five hundred meter contours. Again, the cold area between Point Fermin and Point Vicente (pl. 6) occurs where the five hundred meter line bends to within a mile of the coast (pl. 2). Likewise the areas of cold water shown by plate 9 occur where the five hundred meter contour runs close to the coast (pl. 3), while warm water occurs in the region of shallow water between Cerros Island and the mainland. Finally, the cold water southwest of San Clemente Island shown in plate 5 is associated with a rapid increase in depth from a few meters over the Cortes Bank (pl. 2) to 1500 meters at a distance of less than fifteen miles to the southwest.

However, since the relation thus revealed between the presence of areas of cold water and the bottom topography does not always hold, there must be other factors (see p. 277) that have an important influence on upwelling.

(*d*) *Isohalines.*—The southward dip of the isohalines southeast of Santa Catalina Island (pl. 10), southeast of San Clemente Island (pl. 11 and pl. 12, fig. 14), and off San Diego (pl. 11 and pl. 12, fig. 15) reveals a southward flow of water having a low salinity. In plate 10 the southward dip of the lines nearer the mainland shows a second but narrower southward current, while a flow to the southeast is indicated by plates 13 and 14, figure 19.

The prevailing southerly drift so clearly revealed by both temperatures and salinities is sometimes accompanied by a northward flow of water having a high salinity and restricted to a narrow belt bordering the mainland. Such a northward flow is revealed by the northward dip of the isohalines (pl. 12, figs. 14 and 16) and agrees with that already shown by the isotherms (see p. 260).

In contrast with this translation of water in some definite direction, the circumscribed areas of water having a high salinity northeast of San Clemente Island shown by plates 11 and 13 suggest a whirling motion. Since the island probably deflects the general southerly drift to the east and thus gives rise to a flow to the southeast bordering its coast, there would be a tendency to generate a whirling motion in a counter-clockwise direction. On the other hand, a current flowing southwest past the east point of the island would tend to generate a clockwise whirl. A whirling motion tends to separate the water near its center from the surrounding water and, by thus interfering with the convection currents, permits an increase in both salinity and tem-

perature above that of the surrounding water. Furthermore, the high temperatures of the same region, shown especially well by plate 7, confirm this hypothesis. A similar phenomenon is also indicated in Santa Monica Bay by plates 6 and 10, and the southwesterly flow revealed by the isotherms (pl. 6) would tend to produce a counter-clockwise whirl. The distribution of gas content would evidently be especially valuable in determining the details of such a complex circulation.

Several circumscribed areas of low salinity off the mainland are shown in plate 10; on comparing this with plate 6 the location of these areas of low salinity will be found to correspond with those areas of cold water heretofore discussed (see p. 260). Again, the low salinities off the Cortes Bank correspond to the low temperatures (pls. 5 and 13). These low surface salinities may seem at first to contradict the hypothesis of upwelling, since it is generally believed, as stated by Sumner (1914, p. 82), that "according to the theory of upwelling, we should expect to find water of a *higher* salinity, derived from the deeper parts of the ocean, in the immediate neighborhood of the western coast" [italics mine]. However, the effect of upwelling on the distribution of salinity is not as simple as it would on first thought appear. It depends mainly upon the vertical distribution of salinity and on the velocity of upwelling. As demonstrated on page 277, in any region characterized as this one is by a minimum salinity at some intermediate depth (see p. 272) and a very low velocity of upwelling (see p. 278), *lower* salinities would be expected in the upper levels. Hence the hypothesis of upwelling proposed to account for the low temperatures is well supported by the distribution of salinities.

However, as shown by plates 13 and 14, figure 19, high salinities sometimes occur inshore. The interaction of a number of local conditions which influence salinity, such as humidity and velocity of the air, temperature of the water, solar radiation, etc., may at times overcome the effects of upwelling, which depends largely upon the wind (see p. 277) and is therefore subject to wide variations. Water of low temperature and salinity may have its temperature increased by solar radiation, but the humidity of the air may be so high and its circulation so feeble that evaporation would be very slow and little if any increase in salinity could result. On the other hand, conditions favoring rapid evaporation and therefore high salinities may be associated with influences having little tendency to raise the temperature. In fact, an actual decrease in temperature might result from the tendency of

evaporation to cool the water. Hence such a complex distribution of temperature and salinity must often arise as to require other data before trustworthy conclusions relative to oceanic circulation can be reached. Again, we must not forget that the complexities indicated are due in part at least to errors of interpolation (see p. 259). For example, the oval area of warm water off the mainland near La Jolla, shown by plate 5, indicates the presence of a whirl, but (pl. 13) the salinities in the central part of the oval are low, although high ones would be expected if this water were comparatively stagnant. Again, the isotherms in plate 14, figure 18, indicate at the same location a similar whirl which is apparently contradicted by the corresponding isohalines (pl. 14, fig. 19).

On the whole, the isotherms and isohalines show an increase in temperature and salinity with a decrease in latitude, and afford strong evidence of a general southerly drift that at times is combined with a northerly current near the mainland. This southerly flow largely consists of water having low temperatures and salinities that are very probably due to upwelling of bottom water adjacent to the mainland. There is also evidence, although not as strong, of the presence of areas of whirling water whose central parts are comparatively stagnant.

2. Surface and Subsurface Isotherms and Isohalines West of the Coronado Islands

The large number of observations made in the region of Los Coronados (the Coronado Islands) justifies dividing that area into sections whose sides are one minute in length and representing in greater detail the distribution of temperature and salinity. The isotherms and isohalines which will be considered first are based on observations made in each of a series of depths during June, 1911. The shaded area of each figure represents a horizontal section of the land at the depth considered, i.e., the boundary of this area would be the shoreline if the water were lowered to the corresponding level.

(*a*) *Isotherms.*—The dip to the southwest of the surface isotherms in the upper part of plate 15, figure 20, and the presence of colder water along an area extending to the southwest from the islands are probably due to the junction of a southwesterly current of warm water, pointed out on page 259, with a westerly current of cold water. The isotherms at the depths 9, 18, and 27 meters (pls. 15–16, figs. 21–

23), reveal the same type of circulation in which however, the relative influence of the southerly drift decreases as the depth increases.

At the depth of eighteen meters an area of cold water is shown surrounded by warmer water and by the coast (pl. 16, fig. 22). A similar distribution of temperature is revealed at each of the five lower levels examined, namely 27, 37, 55, 64, and 92 meters (pls. 16–18, figs. 23–27). Such a distribution of temperature reveals either an upwelling of bottom water adjacent to the coast combined with a flow away from the coast, or an upwelling extending over nearly the whole area lying between two lines running southwest from the land. It has been shown that the former type of circulation characterizes the upper layers of water; therefore there must be a compensating circulation of the latter type in the deep water. Moreover, Ekman's theory (see p. 277) shows that the former type of circulation is usually confined to the upper fifty meters, and the latter type prevails from there to the bottom.

On the whole, there is a decrease in temperature at each level along lines converging to the western coasts of the islands. The decrease, however, is not so pronounced as would be expected under similar conditions off the mainland, because their short coast lines permit the intrusion of water at all levels.

The circumscribed areas of warm water shown off South Island by plate 15, figure 20, may be whirls formed by the junction of a southward drift of warm water between the islands and the westward drift of upwelling cold water. Similar areas of warm surface water are shown by plate 19, based upon observations made during May, 1914, and July, 1912.

(*b*) *Isohalines.*—The isohalines in plate 20 show the junction of a southward flow of the upper layers of water having a high salinity with a westward flow of water of low salinity derived from the upwelling next to the coast of South Island. A tendency of the two currents to form whirls is indicated by the circumscribed areas of high salinity in both depths.

The areas of salinities as low as $33.50^{0}/_{00}$ at the depth of 27 meters (pl. 21, fig. 32), bounded by the coast and by water of a higher salinity, show upwelling; while the southward dip of the $33.60^{0}/_{00}$ line at the north and the northward dip of the $33.66^{0}/_{00}$ line at the south indicate an intrusion, along the borders of this area, of water having a higher salinity.

High salinities should border the western coasts in this upwelling

region at depths below about forty meters, as shown on page 277. Therefore the presence of circumscribed areas of high salinity adjacent to the island at the 55 and 92 meter levels (pls. 21 and 22, figs. 33 and 34), and the pronounced decrease in salinity as the distance from the coast increases, afford additional evidence of upwelling. A similar intrusion of water along the north and south borders, but having a low instead of a high salinity, is indicated in these depths by the dip in the bordering isohalines.

Plate 22, figure 35, shows a circumscribed area of water having a high salinity which corresponds to the area of warm water shown by plate 19, figure 28, and thus affords additional evidence in favor of a whirl.

C. RELATION OF TEMPERATURE AND SALINITY TO DISTANCE FROM THE COAST

From serial observations made at a selected number of positions along any straight line, isotherms and isohalines can be drawn in a vertical plane. From these isotherms and isohalines can be inferred the flow of water in a direction parallel to the plane.

1. Isotherms

The isotherms in plate 23, figure 36, are based upon serial observations of temperature made along a line twelve miles in length running perpendicularly to the contours from Point Dume. They show that the inshore temperatures are, on the whole, lower than those offshore. Furthermore, all of the lower isotherms bend upward as they approach the coast, thus revealing a flow of cold deep water toward the coast along lines approximately parallel to the bottom. Again, their greater upward deflection near the coast reveals a proportionately greater upward velocity of cold water there, although it is very small at all positions. Since this upwelling of deep water would necessarily result in a flow of cold water away from the coast in the upper levels, the figure ought to reveal, as it does, a rise in temperature in each of the upper levels as the distance from the coast increases. This rise in temperature would be expected to continue until the value corresponding to the "normal" is reached, i.e., that value corresponding to the local heating effect of the sun (see p. 258).

The peculiar downward dip of all the isotherms three miles from the shore may mean an intrusion of warmer water flowing parallel to the coast, as previously indicated (see p. 264), or it may be due to some other irregularity in the circulation, the cause of which can not readily be discussed here.

The results of a similar series of observations in a plane through a point three miles south of Point Loma and running perpendicularly to the contours are shown by plate 23, figure 37. The lower isotherms are approximately horizontal from the western portion over deep water to within three miles of the region of shallow water, where they are deflected upward. While the temperature of the upper levels does not decrease so rapidly toward the inshore position as in the case represented by plate 23, figure 36, a similar type of circulation is shown. The presence of the region of shallow water several miles in extent between the inshore position and the mainland would tend to reduce upwelling and thus to reduce the cooling effect. Moreover, the observations were begun at 7 in the morning at the offshore position, and the inshore position was not reached until 1 in the afternoon of the same day. Hence, as the work progressed, the effect of solar radiation in increasing the temperature masked that of upwelling.

2. Isohalines

The isohalines shown by plate 24, figure 38, are based on a series of salinity observations corresponding to the temperatures shown by plate 23, figure 36. The upward trend of the lower isohalines corroborates the evidence derived from the isotherms, of an inshore flow of deep water which is deflected upward as the coast is approached. The lines corresponding to $33.50^{o}/_{oo}$ and $33.45^{o}/_{oo}$ reveal an inward flow below forty meters and an outward flow above that depth. The salinities at the upper levels are low inshore; and as the distance from the coast increases they approach the higher value corresponding to local conditions beyond the region of upwelling.

The isohalines shown by plate 24, figure 39, which correspond to the isotherms of plate 23, figure 37, reveal again the same type of circulation. The large area of shallow water between the mainland and this inshore position probably accounts for the high surface salinities near the latter area. The high salinities half-way between the offshore and inshore positions are probably due to the order in which the observations were made, as stated above.

D. PERIODIC VARIATIONS IN TEMPERATURE AND SALINITY

1. Seasonal Variations

Owing to the prevailing variations in temperature and salinity with respect to position, observations made in a deep-water region of small area but little affected by upwelling and well distributed throughout each year afford the most satisfactory basis for a study of periodic temperature and salinity variations. Our observations made in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6, eight miles off the Coronado Islands, though not numerous during each month of any one year, meet the requirements better than those made in any other region. Accordingly, these observations, supplemented by those made off the Coronado pier in section 38_8, and by "normal" values for the Pacific at this latitude, are employed for this purpose.

The mean monthly surface temperature of the ocean corresponding to an average year within the period from 1908 to 1915 is shown by plate 25, figure 40. This curve agrees well with that based on supplementary observations made off the pier at Coronado Beach (pl. 25, fig. 41), where, owing to the large area of shallow water and the gentle slope of the bottom, the average reduction in temperature due to upwelling is also small.[1] These monthly temperatures are from one to two degrees lower than the "normal" for the Pacific Ocean at the same latitude, as revealed by comparison with plate 25, figure 42, representing the temperatures a thousand miles west of San Diego, as shown by the monthly isotherms of the North Pacific (Thorade, 1909). Plate 25, figure 42, shows further that the "normal" annual range is 7° C, from a minimum of 15° C in March or April to a maximum of 22° C in August, while off the Coronado Islands (pl. 25, fig. 40) the annual range is 6°2 C, from a minimum of 14°3 C in February to a maximum of 20°5 C in August.

Off the Coronado Islands (pl. 25, fig. 43) the mean monthly salinity has an annual range of 0.25‰, from a minimum of 33.50‰ in February to a maximum of 33.75‰ in July or August. These values are somewhat lower than those found off Coronado Beach, where (pl. 25, fig. 44) the minimum is 33.55‰ in January and the maximum is 33.85‰ in July or August.

[1] On some days the temperatures off Coronado Beach are as low as those found at any of the upwelling regions, but such cases are exceptional.

The average seasonal variation in temperature at all depths less than five hundred meters during the period from 1908 to 1915 is shown by plate 26, figure 45. This, together with plate 25, figure 40, shows that the month of minimum temperature varies from February at the surface to May at depths exceeding thirty meters, and that the month of maximum temperature varies from August at the surface to November at depths exceeding fifty meters. It also shows that the annual range in temperature decreases from 6°2 C at the surface to 1°0 C at two hundred meters, while it can scarcely be detected below four hundred meters.

The average seasonal variation in salinity at all depths less than five hundred meters is shown by plate 26, figure 46. Though salinity data are very deficient for October, November, December, and January, and are less complete than the temperature data for the remaining months, certain general facts can be inferred. At the surface (see also pl. 25, fig. 43) the minimum salinity occurs in February and the maximum in July or August. At 25 meters a minimum annual range of 0.15‰ is shown. Below 75 meters the maximum occurs in April, and the minimum in November; while the annual range at 150 meters approximates to 0.25‰, the range at the surface. Below 400 meters the annual range can scarcely be detected. The peculiar dip of all isohalines below 50 meters between May and July is very likely due to a difference in years rather than months.

The distribution of temperature and salinity is very different in spring, when the increasing solar radiation tends to raise the temperature and salinity, from that in autumn, when because of the decreasing solar radiation the water tends to cool. In fact, there is a characteristic distribution of temperature and salinity for each month which is revealed in detail by plates 27–32.

The surface temperature of Glorietta Bight, a shallow inlet of San Diego Bay near Coronado Beach, well removed from direct influences of the main tidal currents, has an annual range of 10° C, from a minimum of 14° C in January to a maximum of 24° C in July or August (pl. 33, fig. 92). The corresponding surface salinity (pl. 33, fig. 91) has an annual range of 1.73‰, seven times greater than in the ocean. It varies from a minimum of 33.67‰ in February to a maximum of 35.40‰ in July. Temperature observations made in the central portion of the bay reveal an annual range (pl. 33, fig. 93) of 9°7 C from a minimum of 12°8 C in January to a maximum of 22°5 C in August.

Both temperature and salinity observations in San Diego Bay give widely different results, depending upon the state of the tide and the position of the observations; the values generally increase as the tide falls and as the distance from the entrance increases. For example, at low tide on July 18, 1908, at 8 in the morning, the temperature and salinity near the central part of the bay were 20°.8 C and 34.71‰ respectively; four hours later, during high tide, at the same place the values were reduced to 18°.0 C and 34.04‰ respectively. During the same month temperatures as high as 27°.07 C and salinities as high as 36.50‰ were observed in the shallow water off National City, eight miles from the harbor entrance, while at the entrance itself the values were approximately 19°.0 C and 33.75‰.

Our hydrographic observations both in San Diego Bay and in the ocean demonstrate that, while the monthly averages of temperature and salinity at any given position show the same general type of seasonal variation, each year is distinct from the others. In fact, averages for each of the several different months have actually differed from those for the same months of other years by amounts comparable with the annual range. Compare especially figure 50 with 51 (pl. 27), figure 62 with 63 (pl. 29), and figure 66 with 68 (pl. 30).

Again, we have not infrequently found significant differences in temperature and salinity corresponding to different days of the same month at a given position, even ten miles or more from shore. For example, on June 25, 1909, four surface temperatures were observed at 32° 52′ N and 117° 30′ W between 17°.6 C and 17°.7 C, while three days later, at the same position and time of day, three temperatures were observed between 19°.0 C and 19°.2 C. The corresponding salinities were between 33.63‰ and 33.65‰ on the first day, while on the last day they were between 33.68‰ and 33.81‰. Moreover, large differences may occur at approximately the same time and within a distance of two or three miles of each other, even in regions well removed from land and over deep water. For example, on July 11, 1908, midway between San Clemente Island and the Cortes Bank, the surface temperature was 17°.2 C and the salinity 33.75‰; twenty minutes later and two miles farther from San Clemente the temperature was 15°.4 C and the salinity 33.84‰.

Nearer shore there are still greater irregularities. For example, on July 25, 1912, about half a mile southeast of South Coronado Island, temperatures *simultaneously observed at positions less than sixty feet apart* differed by 1°.5 C; the first was 19°.7 C and the second 21°.2 C.

Moreover, this is not an isolated case; similar differences have been repeatedly observed (Michael and McEwen, 1915, table I, water-samples 3329–30, 3369–70, and 3377–78).

These facts emphasize the necessity of fairly continuous and numerous observations *at each position.* They *demonstrate* that even a very crude approximation toward a biological or planktonic "census of the sea" can be obtained, if at all, only from a vast number of simultaneous observations well distributed throughout the region to which the census refers. Even granting that plankton is "uniformly distributed" if "physical conditions" are uniform, the *main* errors can not, as intimated by Johnstone (1908, pp. 119–121), be eliminated by refinement of apparatus. The employment of nets whose filtration "constants" are known even to within an infinitesimal quantity can not eliminate the effects of unavoidable variation in temperature and salinity, not to mention those of other environmental elements.

2. Mean Annual Values

The average of a large number of observations of temperature or salinity well distributed throughout each year of a given period is required for an exact determination of the mean annual temperature or salinity corresponding to that period. If the observations are not well distributed or if they are missing for certain months, the simple average of the observations will usually give an erroneous estimate. However, by means of graphical interpolation, as shown by plate 26, figures 45 and 46, approximate estimates can be made of the true values for each month of what corresponds to an average year of the period, and the average of these results is the best approximation to the mean annual temperature or salinity that can be obtained from the data. The relation of the mean annual temperature to depth shown by plate 34 and the corresponding salinity relation shown by plate 35 were determined in this way from plate 26. The extreme monthly averages indicated by the dotted lines were also determined from the same curves. Since little if any seasonal variation in temperature or salinity occurs below four hundred meters, the simple average of all values observed at each of these depths was plotted, and the curves (pl. 36, figs. 96–97) drawn through the points representing the observed values give the relation between the mean annual temperature and salinity to depth, in the interval from four hundred to fourteen hundred meters.

3. Diurnal Variation

In the same region (eight miles west of the Coronado Islands) the diurnal range in surface temperature is about 1°.0 C. The minimum temperature occurs between 1 and 2 in the morning and the maximum between 5 and 7 in the afternoon. Between 10 and 11 in the morning and 10 and 11 at night the temperature is approximately the same as the average for a twenty-four hour interval. The maximum occurs about sixteen hours after the preceding minimum and about eight hours before the following minimum.

An empirical law of diurnal variation in surface temperature based on a large number of observations may be used for correcting a temperature observed at any hour approximately to its value corresponding to any other hour. For example, adding to an observed temperature the correction entered in the following table gives its most probable value at 10 A.M.

TABLE I

Corrections to Surface Temperature Observations to Give Their Most Probable Values at 10 A.M.

	Time of observation							
	A.M.				P.M.			
	0–3	3–6	6–9	9–12	12–3	3–6	6–9	9–12
Correction	+0°.45	+0°.40	+0°.30	0°.00	—0°.25	—0°.45	—0°.40	0°.00

Diurnal variation decreases in magnitude as the depth increases; and at depths exceeding twenty-five meters it is not indicated at all by our data. Furthermore, the observations we have made do not justify computing a table of corrections for any level but the surface.

While a small diurnal variation (about $0.05^{o}/_{oo}$) in surface salinity is indicated by our data, it is apparently more complicated than that of the temperature, and our observations are not adapted to determining its law.

E. THE THERMOCLINE AND ACCOMPANYING SALINITY DISTRIBUTION

The temperature usually decreases continually as the depth increases and our observations have never revealed a "reversal," i.e., an increase in temperature with an increase in depth.[2] The depth-interval in which the temperature changes most rapidly with the depth is called the "thermocline." The water in this interval forms a transition layer or boundary separating two masses of water of very different temperatures. During the summer months, from May to September inclusive, the thermocline is near the surface and the rate of temperature change, 0°.16 C per meter, is comparatively rapid; while during the winter months, from October to April, it occurs at a greater depth, and the rate of change is only 0°.07 C per meter (pl. 26, fig. 45).

In August the thermocline is usually between 5 and 25 meters and the rate of change, 0°.30 C per meter, is greater than during any other month, while in February it occurs between 25 and 100 meters, and the rate of change, 0°.05 C per meter, is smaller than during any other month (pl. 36, fig. 98).

The distribution of salinity with respect to depth is closely correlated with the temperature distribution. During August, when the thermocline is most pronounced, the salinity decreases most rapidly to a *minimum* at about 30 meters and increases from there to the bottom, while during December, January, and February, when the temperature in the upper 50 meters decreases very slowly with respect to the depth, the salinity is nearly constant, though a minimum is indicated at 30 meters (pl. 37, fig. 99).

The existence of a minimum salinity between 20 and 60 meters, at least in the region from Point Conception to the Coronado Islands, is established beyond doubt, since it is clearly revealed by the monthly average values (pls. 29–32), as well as by nearly all of the numerous individual series of observations. A few such series are presented in the following table.

[2] A few such cases have been indicated, but proved to be due to errors.

TABLE II

SEVEN SELECTED SERIES OF SALINITY OBSERVATIONS REVEALING A SUBSURFACE MINIMUM

Water sample 1606–1620 Aug. 16, 1910 Section 41_5		Water sample 2207–2230 June 22, 1911 Section 42_{10}		Water sample 2681–2701 Aug. 10, 1911 Section 40_4		Water sample 2837–2844 Aug. 12, 1911 Section 40_6		Water sample 4282–4298 Aug. 7, 1913 Section 62_{25}		Water sample 4468–4485 Aug. 9, 1913 Section 58_{23}		Water sample 4518–4533 Aug. 10, 1913 Section 53_{21}	
Depth in meters	Salinity per mille	Depth in meters	Salinity per mille	Depth in meters	Salinity per mille	Depth in meters	Salinity per mille	Depth in meters	Salinity per mille	Depth in meters	Salinity per mille	Depth in meters	Salinity per mille
0	33.65	0	33.75	0	33.63	0	33.70	0	33.60	0	33.70	0	33.64
0	33.71	0	33.68	0	33.76	9	33.48	5	33.58	0	33.67	0	33.62
0	33.73	5	33.65	4	33.44	18	33.49	7	33.59	5	33.62	5	33.58
10	33.71	7	33.65	5	33.59	27	33.40	10	33.57	7	33.64	7	33.37
20	33.48	9	33.68	7	33.60	37	33.38	12	33.57	10	33.58	10	33.40
30	33.43	13	33.68	9	33.61	55	33.50	15	33.53	12	33.54	12	33.50
50	33.52	16	33.58	11	33.64	92	33.60	17	33.57	15	33.57	15	33.50
75	33.71	18	33.58	18	33.47	185	33.94	20	33.55	17	33.57	17	33.50
125	33.81	22	33.60	23	33.43	365	34.25	25	33.53	20	33.53	20	33.50
225	34.06	27	33.54	27	33.43	.....	.....	30	33.50	25	33.50	25	33.49
.....	.....	37	33.52	37	33.52	.....	.....	40	33.45	30	33.50	30	33.52
.....	.....	37	33.54	46	33.43	.....	.....	50	33.45	40	33.51	40	33.53
.....	.....	46	33.53	55	33.44	.....	.....	60	33.60	50	33.51	50	33.60
.....	.....	46	33.53	64	33.52	.....	.....	75	33.69	60	33.49	60	33.60
.....	.....	64	33.64	92	33.63	.....	.....	150	33.95	75	33.57	75	33.68
.....	.....	73	33.70	110	33.71	.....	.....	.....	.....	100	33.71	100	33.79
.....	.....	82	33.83	137	33.94	.....	.....	.....	.....	150	33.93	.....	.....
.....	.....	92	33.69	.....	.....	.....	.....	.....	.....	200	34.09	.....	.....
.....	.....	110	33.94	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	137	33.93	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

While the minimum is most pronounced in August, it is clearly revealed in every month except November, December, January, and February, and in these winter months the salinity of the upper 30 meters does not increase as the depth increases. In the winter months the salinity at depths above 200 meters is less than during any other time of the year, and there is a continual increase from about 30 meters to the bottom. The prevailing depth of the minimum in deep-water regions is between 20 and 60 meters, but as the coast is approached it occurs nearer the surface.

In general, the conditions necessary for the production of such a minimum are probably limited to certain parts of the ocean as well as to certain seasons. In most expeditions too few observations have been made in the upper hundred meters to determine whether such a minimum existed or not. In fact, our own observations made prior to the summer of 1910, while indicating a minimum, were too far apart to establish its presence, and the small number of low salinities ob-

served below the surface were thought to be due to erroneous determinations. It was only after we began making observations with the Ekman reversing water bottles at short intervals of five meters or less between the surface and one hundred meters that we became convinced of the presence of a subsurface minimum. Finally, these results demonstrate the need of more intensive observations in the upper hundred meters of other regions.

F. CERTAIN THEORETICAL IMPLICATIONS OF THE OBSERVATIONS

In general, our temperature observations made at all levels off the west coasts of the mainland and the islands reveal an increase in temperature as the distance from the coast increases. Furthermore, our observations of salinity made at all levels above the depth of its minimum value (see p. 272), which varies from sixty meters in deep to less than ten in shallow water, show that on the average the water adjacent to the coast has the lowest salinity. That is, in this upper mass of water the salinity varies in the same general way as the temperature, though not as regularly. Again, at all levels below the depth of minimum salinity the highest salinities occur adjacent to the coast, and there is a fairly regular decrease as the distance from the coast increases.

The presence of cold water has been repeatedly observed in various coastal regions. In order to account for this phenomenon some hypothesis involving the upwelling of deep water into these regions has been proposed by several investigators; as revealed in the preceding pages, there is strong evidence in favor of such a circulation off the California coast.

An upwelling of deep cold water would evidently reduce the temperature at any higher level and would also tend to maintain the salinity in the upper levels at a value below the normal, if the rate of upwelling is not too great. The reason for this is as follows: Since sea-water is a dilute solution of various salts, its osmotic pressure varies as the product of its concentration or salinity, by its absolute temperature. As shown by the following table, this product is nearly constant at all depths below that corresponding to the depth of minimum salinity, but increases from there to the surface. Therefore the osmotic pressure must be essentially constant below this depth, but

TABLE III

RELATION BETWEEN DEPTH AND THE PRODUCT OF ABSOLUTE TEMPERATURE AND SALINITY

Based on a single series of observations made in section 40_4 on August 11, 1911				Based on the mean annual temperature and salinity as shown by plates 42, 43, and 44			
Depth in meters	Absolute temperature	Salinity	Product	Depth in meters	Absolute temperature	Salinity	Product
0	293.40	33.81	9915	0	290.0	33.66	9760
0	293.50	33.66	9880	10	289.7	33.58	9730
0	293.15	33.68	9870	20	288.2	33.54	9665
9	293.20	33.60	9850	30	287.2	33.53	9630
14	290.40	33.54	9740	40	286.1	33.55	9600
18	289.90	33.53	9720	50	285.5	33.57	9585
23	288.40	33.76	9735	60	285.0	33.61	9580
37	286.90	33.57	9630	70	284.6	33.66	9580
46	285.25	33.50	9555	80	284.3	33.71	9585
55	284.50	33.50	9530	90	284.0	33.73	9585
73	283.95	33.57	9530	100	283.8	33.79	9590
92	283.40	33.65	9535	150	282.9	34.01	9620
275	282.20	34.00	9595	200	282.3	34.16	9645
550	279.45	34.14	9540	400	280.5	34.31	9625
1235	277.05	34.42	9535	600	279.1	34.36	9590
				800	278.0	34.40	9565

owing to evaporation at the surface it increases progressively toward the surface. Thus such a high concentration is maintained at the surface that there is continual diffusion of salts toward the bottom

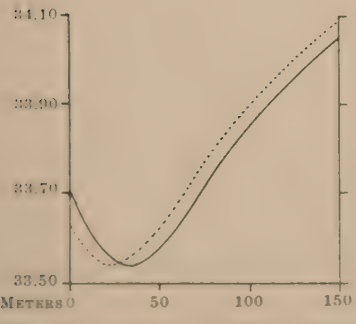

Fig. A. Diagram to illustrate the effect of upwelling on the vertical distribution of salinity.

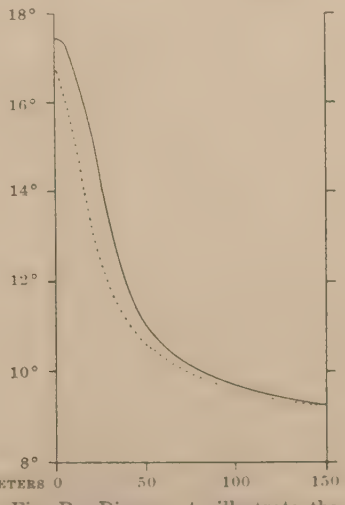

Fig. B. Diagram to illustrate the effect of upwelling on the vertical distribution of temperature.

water. Imagine these processes of evaporation, absorption of solar radiation, convection, and diffusion to take place during brief time-intervals alternating with other intervals during which the entire column of water is slightly elevated. Because of the relation of temperature and salinity to depth in the region from Point Conception to the Coronado Islands (see pp. 272 to 274), which relation is shown diagrammatically by text-figures A and B (full lines), the elevation of the entire column would result in a lower temperature at all levels, a lower salinity at each level above that of its minimum value, and a higher salinity at each level below that depth (text-figs. A and B, dotted lines). During the next interval when the column of water remained stationary the former processes of absorption, evaporation, and diffusion would tend to produce the relations represented by the full lines, and so on.

The absorption of solar radiation which tends to heat the water is accompanied by the processes of evaporation and convection which tend to cool it. If these opposing influences are not balanced, the temperature must change. For example, if the heat lost because of evaporation and convection is less than that absorbed from solar radiation the temperature will rise. But as it rises the rate of loss of heat will increase; and if the heat due to the absorption of solar radiation is gained at a constant rate, the temperature will ultimately increase until the heat lost equals that gained.

Now, in order to deduce the effect of upwelling, let us suppose a whole column of water is moved upward a small distance during a brief time-interval, and that these processes of heating, evaporation, etc., take place during the next interval, and so on. The temperature in each part of the column will then be reduced during the intervals when the column is moved upward, and raised during the other intervals. But, in order that the temperature may rise during the intervals of absorption, the actual temperature must be below the normal. Therefore such a temperature will finally be reached that its increase during the intervals of absorption will equal its decrease during the intervals of upward motion; that is, a "steady state" will arise in which the temperature is less than it would have been had the column of water not been elevated.

Similarly, the process of evaporation, which increases the salinity, is accompanied by the opposing processes of convection and diffusion, and if the rate of evaporation remains constant, a constant value of the salinity will finally be reached. Imagine the above processes of

heating, evaporation, etc., to take place during brief intervals of time alternating with intervals during which the column is elevated. During the intervals of elevation the salinity will be reduced at all depths above that of its minimum value, and raised at all greater depths, but during the other intervals it will be raised at all depths above that of its minimum value and lowered at all greater depths. Hence, as was shown to be true of temperatures, a steady state must ultimately arise in which the salinity is lower above the depth of its minimum value but is higher below that depth. If, as is the case in nature, the alternating time-intervals be indefinitely reduced until all processes occur simultaneously, the final temperature and salinity distribution will be unaltered.

The conclusion just reached regarding the effect of upwelling on the salinity holds only when other local conditions tend to produce a minimum value at some intermediate depth, and when the vertical velocities are not too great. In the absence of such a minimum value of the salinity or in case the upwelling is sufficiently active, high salinities would be expected at all depths of inshore regions.

By applying Ekman's hydrodynamical theory of oceanic circulation to observations other than of temperature and salinity made off the west coast of North America, the conclusion (McEwen, 1912) was reached that there must be an upwelling of deep water along the coast from 40° N to about 25° N. An important principle deduced by Ekman is that a wind blowing parallel to a coast will not only move the water in its own direction but will deflect a surface layer of less than one hundred meters in thickness to the right of its own direction. Hence a wind blowing in the proper direction with respect to a coast will remove the surface water and thus reduce the water pressure at all distances from the bottom. This reduction of pressure will then give rise to a flow of bottom water toward the coast, and consequently to the surface near the coast. By considering quantitatively the relation between wind velocities and the mean monthly surface temperatures between the west coast of North America and 140° W[3] the wind velocity was demonstrated to be an important if not the main cause of upwelling (McEwen, 1912). It also follows from Ekman's theory that the greater the inclination of the bottom, in the neighborhood of a coast, the narrower will be the belt near the coast into which a given volume of bottom water intrudes, and therefore the greater will be the

[3] See U. S. Meteorological Charts of the North Pacific (1908–1911) for data on the winds, and Thorade (1909) for the temperature distribution.

reduction of temperature and salinity in the upper levels. This deduction is strikingly verified by the observations discussed on pages 260 and 262.

Other theoretical investigations, not yet published, not only confirm the above conclusions but afford estimates of several other quantities measured as well as unmeasured. For example, a theoretical result which has not been checked directly is shown by the diagrammatic representation of the vertical circulation (text-fig. C). Adjacent stream lines include one-tenth (0.1) of the total volume of water flowing upward, and next to the coast, where the distance between the stream lines is a minimum, the vertical velocity is a maxi-

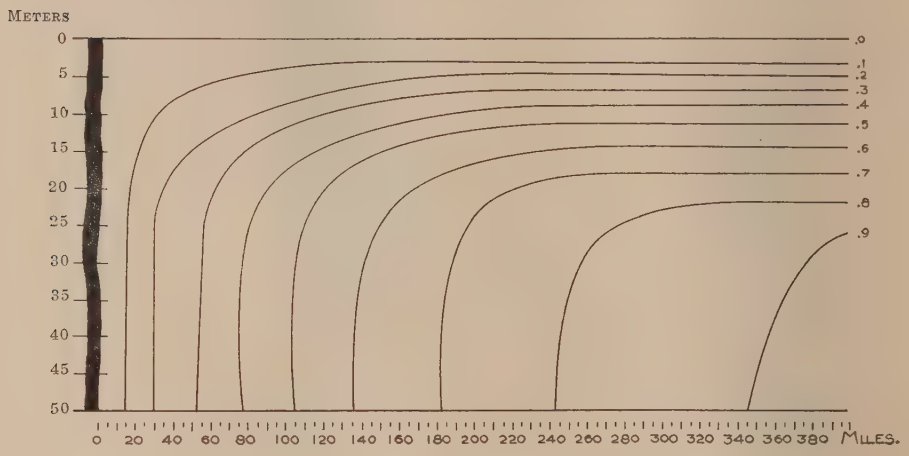

Fig. C

mum which, according to theoretical results based on observations made prior to 1915, could not have averaged more than one hundred meters per month. The actual stream lines are, of course, not parallel to the plane of the diagram because of the horizontal flow parallel to the coast.

Again, the amount of solar radiation absorbed per meter of seawater was deduced from the distribution of temperatures in the Pacific Ocean represented on Thorade's (1909) charts and from our own temperature observations. The resulting relation of the intensity of radiation to depth is expressed by the formula

$$(1)\quad I = Ae^{-0.0654z}$$

where I is the intensity at the depth z meters, A is the intensity at

the surface, and e is the Naperian base, 2.718. The values computed from this formula agree well with the results of photographic observations made in the Atlantic Ocean (Grien, 1913). Since direct observations of the intensity of light have not been made in the water of the San Diego region, the diagram (pl. 38, fig. 100) has been included in this paper in order to give the best approximation possible without direct measurement. It gives the average distribution of relative light intensities with respect to depth and the time of day, and is based on the above formula and an empirical one representing approximately the results of observations on the diurnal variation in the intensity of solar radiation on a horizontal surface at sea-level, between 20° N and 40° N. This formula is

$$(2)\quad I = 455 + 380\cos\frac{\pi t}{12} + 165\cos\frac{\pi t}{6}$$

where I is the intensity at the depth of one meter, in arbitrary units, and t is the time in hours measured from noon. Corresponding to these units formula (1) becomes

$$(3)\quad I = 1067e^{-0.0654z}.$$

In a later paper a detailed account of the unpublished investigations referred to above will be presented.

I wish to express my thanks to Mr. E. L. Michael for his valuable suggestions relative to the preparation of the manuscript.

Transmitted February 18, 1916.

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G. LITERATURE CITED

Davidson, G.

1897. The submerged valleys of the coast of California, U. S. A., and of Lower California, Mexico. Proc. Calif. Acad. Sci., Geol. (3), 1, no. 2, 73–103, pls. 4–12.

Greín, K.

1913. Untersuchungen über die Absorption des Lichts in Seewasser. Teil. Die selektive Absorption des Sonnenlichts im Meer nebst einer Beschreibung des Instruments und der Methode. Ann. Inst. Oceanogr., 5, fasc. 6, 1–23, 7 figs. in text.

Johnstone, J.

1908. Conditions of life in the sea. (Cambridge Univ. Press), 326 pp., 29 figs.

McEwen, G. F.

1912. The distribution of ocean temperatures along the west coast of North America deduced from Ekman's theory of the upwelling of the cold water from the adjacent ocean depths. Int. Rev. Hydrobiol. u. Hydrog., 5, 243–286, 21 figs. in text.

Michael, E. L. and McEwen, G. F.

1915. Hydrographic, plankton and dredging records of the Scripps Institution for Biological Research of the University of California, 1901–1912. Univ. Calif. Publ. Zool., 15, 1–206, 4 figs. and 1 map in text.

1916. Continuation of hydrographic, plankton, and dredging records of the Scripps Institution for Biological Research of the University of California, 1913–1915. Univ. Calif. Publ. Zool., 15, 207–254, 4 figs. in text.

Sumner, F. B., Louderback, G. D,. Schmitt, W. L., and Johnston, E. C.

1914. A report upon the physical conditions in San Francisco Bay, based upon the operations of the United States fisheries steamer "Albatross" during the years 1912 and 1913. Univ. Calif. Publ. Zool., 14, 1–198, 20 figs. in text, pls. 1–13.

Thompson, D. W.

1904–05. Second report (northern area) on the fishery and hydrographical investigations in the North Sea and adjacent waters. Part 1. Hydrography. (London, Darling and Son), iv + 209, 18 pls., 33 figs. in text.

Thorade, H.

1909. Ueber die Kalifornische Meeresströmungen, Oberflächentemperaturen und Strömungen an der Westküste Nordamerikas. Ann. Hydr. u. marit. Meteor., 37, 17–34, 63–77, 5 figs in text, pls. 5, 10, 11.

EXPLANATION OF PLATES

PLATE 1

Fig. 1. Topography of ocean bottom, and approximate number and distribution of observations.

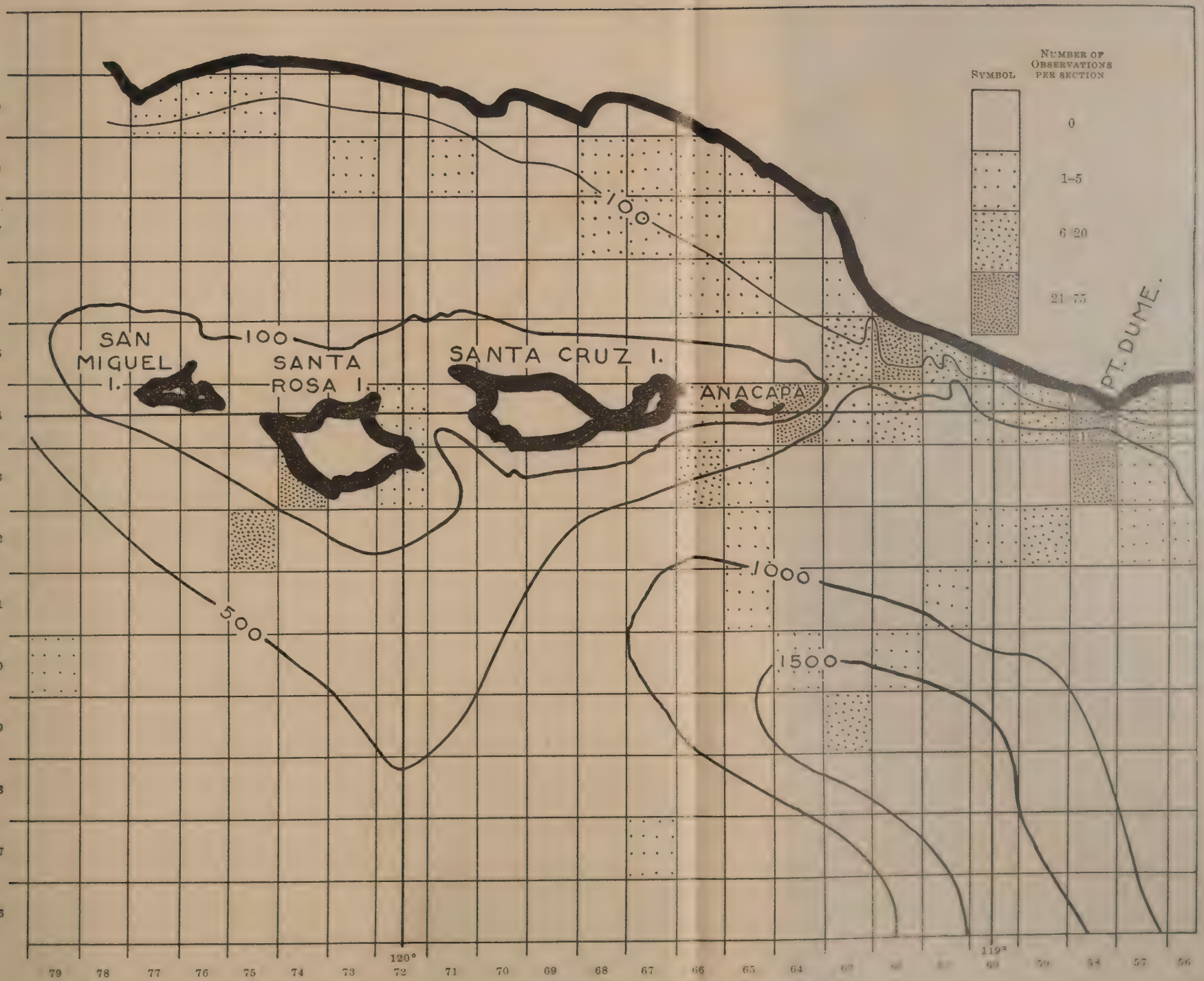

SYMBOL
NUMBER OF OBSERVATIONS PER SECTION
0
1–5
6–20
21–75
SAN MIGUEL I.
SANTA ROSA I.
SANTA CRUZ I.
ANACAPA
PT. DUME.
100
500
1000
1500
29
28
27
26
25
24
23
22
21
20
19
18
17
16
120°
119°
79 78 77 76 75 74 73 72 71 70 69 68 67 66 65 64 63 62 61 60 59 58 57 56

Fig. 1

PLATE 2

Fig. 2. Topography of ocean bottom, and approximate number and distribution of observations.

Since the "sections" chosen for the ocean are too large to reveal adequately the distribution of observations made in San Diego and False (Mission) bays, these bays are left blank, although approximately four hundred hydrographic observations were made in the former and forty in the latter.

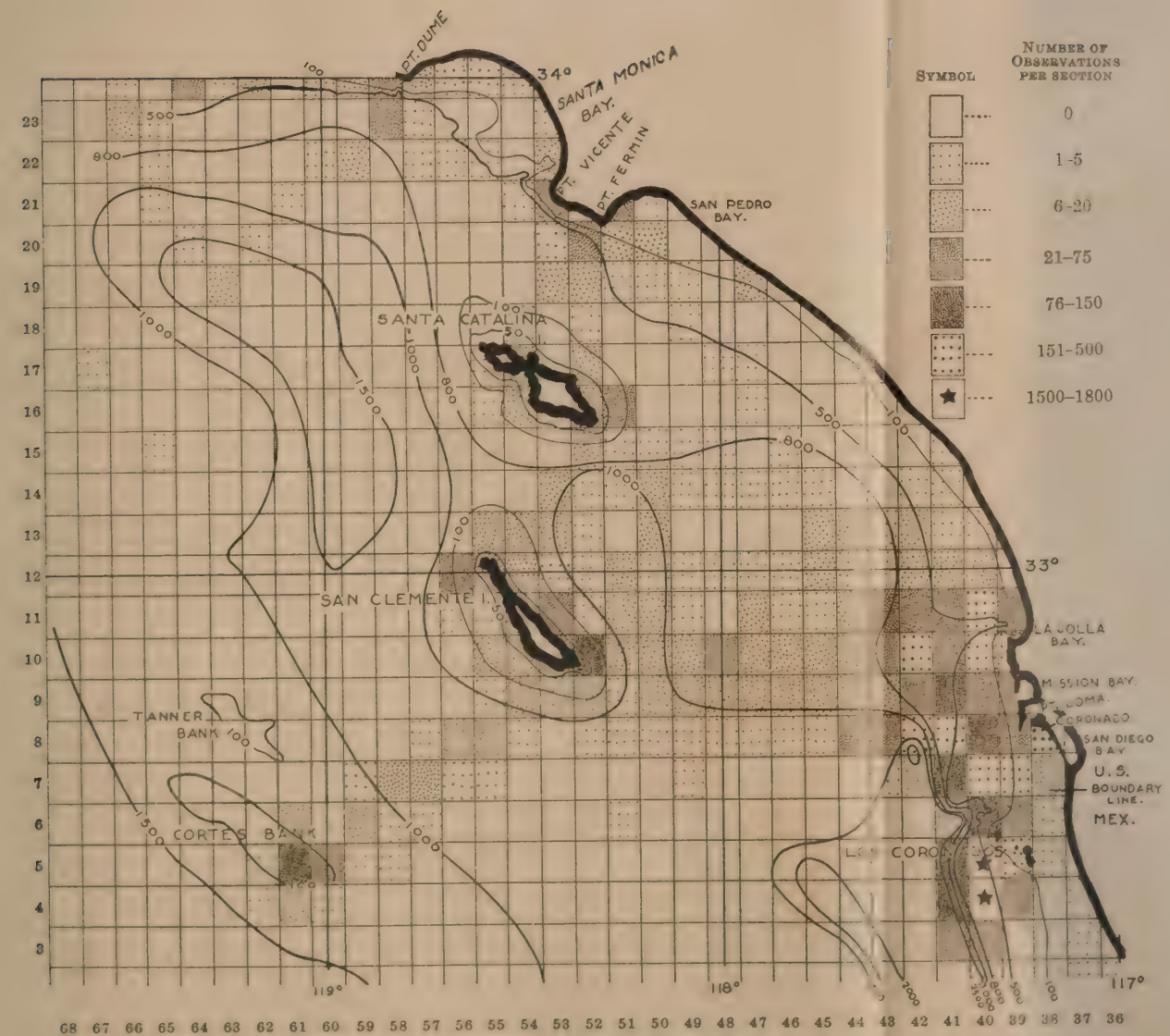

SYMBOL
NUMBER OF OBSERVATIONS PER SECTION
0
1-5
6-20
21-75
76-150
151-500
1500-1800
PT. DUME
SANTA MONICA BAY.
PT. VICENTE
PT. FERMIN
SAN PEDRO BAY.
SANTA CATALINA I.
SAN CLEMENTE I.
TANNER BANK
CORTES BANK
LA JOLLA BAY.
SAN DIEGO BAY
CORONADO
U.S. BOUNDARY LINE.
MEX.
34°
33°
119°
118°
117°

Fig. 2

PLATE 3

Fig. 3. Topography of ocean bottom, and approximate number and distribution of observations.

1000
500
100
50
32°
TODOS SANTOS BAY.
PT. BANDA.
SYMBOL
NUMBER OF OBSERVATIONS PER SECTION
0
1–5
6–20
21–75
2000
100
500
31°
CAPE SAN QUENTIN.
MEXICO.
30°
GUADALUPE I.
50
100
500
1000
2000
4000
29°
CERROS I.
100
28°
PT. SAN EUGENIO.
118°
117°
116°
115°

Fig. 3

SYMBOL
NUMBER OF OBSERVATIONS PER SECTION
0
1–5
6–20
21–75
100
SAN MIGUEL I.
SANTA ROSA I.
SANTA CRUZ I.
ANACAPA
PT. DUME.
500
1000
1500
34°
120°
119°
29
28
27
26
25
24
23
22
21
20
19
18
17
16
79 78 77 76 75 74 73 72 71 70 69 68 67 66 65 64 63 62 61 60 59 58 57 56

Fig. 1

PLATE 4

Fig. 4. Topography of ocean bottom in a small region west of Los Coronados (the Coronado Islands).

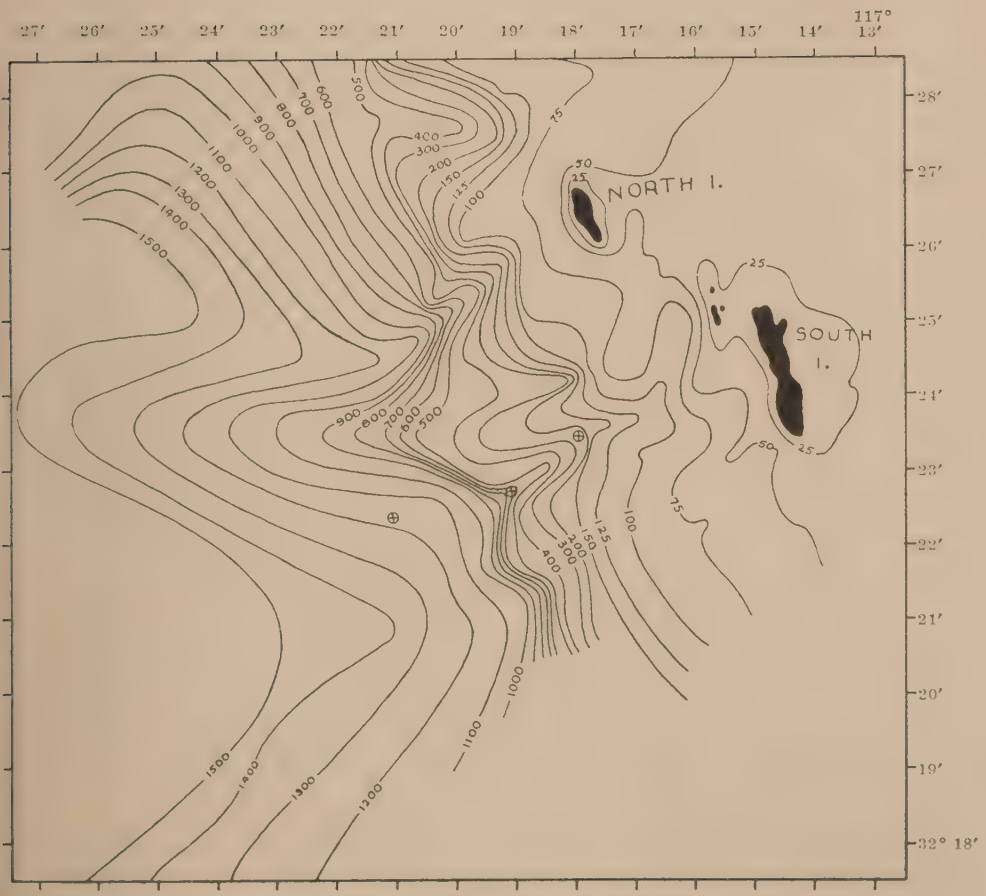

117° 13′
27′ 26′ 25′ 24′ 23′ 22′ 21′ 20′ 19′ 18′ 17′ 16′ 15′ 14′
28′ 27′ 26′ 25′ 24′ 23′ 22′ 21′ 20′ 19′
32° 18′
NORTH I.
SOUTH I.
500 600 700 800 900 1000 1100 1200 1300 1400 1500
400 300 200 150 125 100 75 50 25
50 25
25
500 600 700 800 900 1000 1100 1200 1300 1400 1500
400 300 200 150 125 100 75 50 25

Fig. 1

PLATE 5

Fig. 5. Surface isotherms for July, 1908.

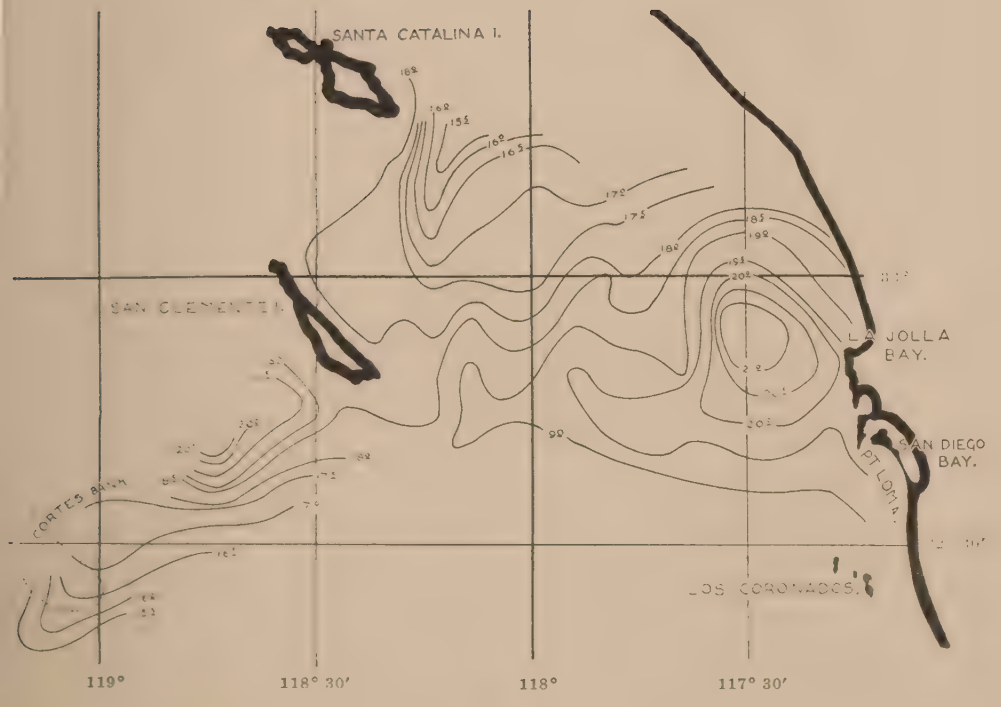

SANTA CATALINA I.
SAN CLEMENTE I.
LA JOLLA BAY.
SAN DIEGO BAY.
PT. LOMA
CORTES BANK
LOS CORONADOS I.
119°
118° 30′
118°
117° 30′

Fig. 5

PLATE 6

Fig. 6. Surface isotherms for August, 1913.

PT. DUME.
34°
SANTA MONICA BAY.
PT. VICENTE.
PT. FERMIN.
33° 30'
SANTA CATALINA I.
SAN CLEMENTE I
LA JOLLA BAY.
SAN DIEGO BAY.
PT. LOMA.
119°
118° 30'
118°
117° 30'

Fig. 6

PLATE 7

Fig. 7. Surface isotherms for June, 1911.

SANTA CATALINA I.
33° 30′
33°
32° 30′
LA JOLLA BAY
SAN DIEGO BAY.
PT LOMA
LOS CORONADOS
118° 30′
118°
117° 30′

Fig. 7

PLATE 8

Fig. 8. Surface isotherms for July, 1909.

Fig. 9. Surface isotherms for February, 1909.

Fig. 10. Surface isotherms for September, 1909.

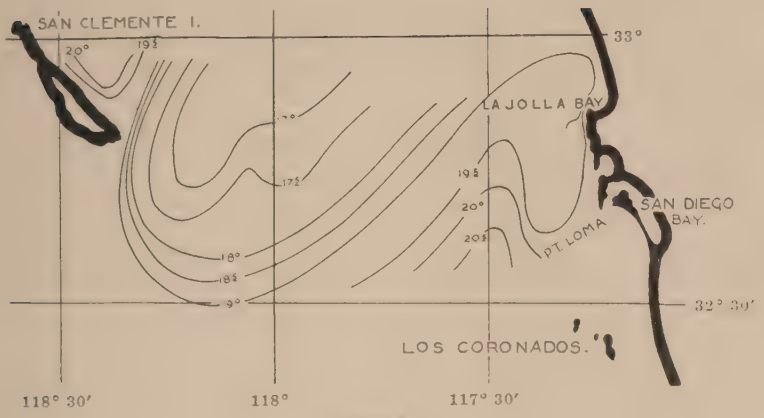


Fig. 8

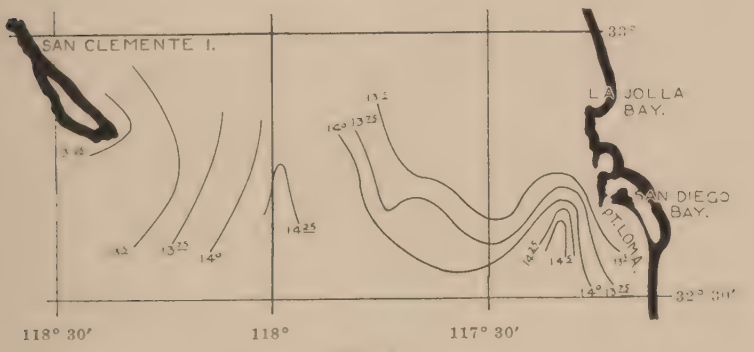


Fig. 9

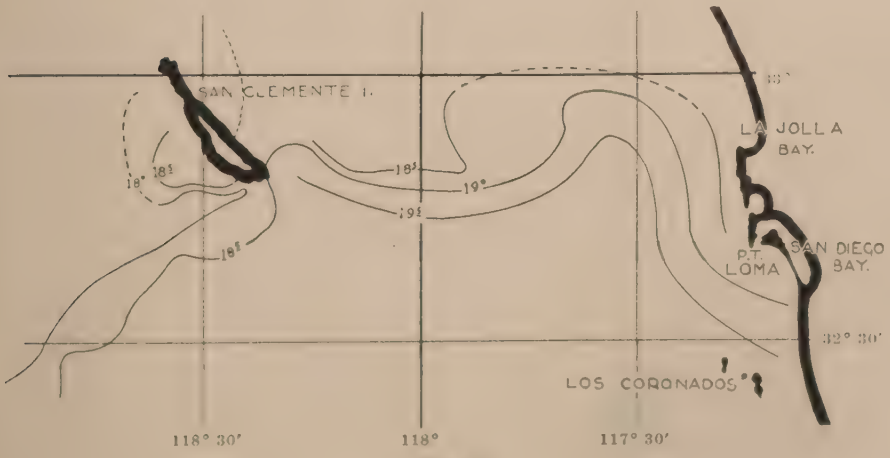


Fig. 10

PLATE 9

Fig. 11. Surface isotherms for August and September, 1908.

SAN DIEGO BAY.
U.S. BOUNDARY LINE.
TODOS SANTOS BAY.
PT. BANDA.
MEXICO
CAPE SAN QUENTIN
32°
31°
30°
29°
28°
115°
117°
GUADALUPE I.
CERROS I.
PT. SAN EUGENIO

Fig. 11

PLATE 10

Fig. 12. Surface isohalines for August, 1913.

33.60
33.55
33.60
PT. DUME
33.60
SANTA MONICA BAY
34°
33.70
33.65
PT. VICENTE
33.50
PT. FERMIN.
33° 30'
33.55
SANTA CATALINA I.
33.60
33.65
33.70
33°
SAN CLEMENTE I.
LA JOLLA BAY
33.55
SAN DIEGO BAY.
119°
118° 30'
118°
117° 30'

Fig. 12

PLATE 11

Fig. 13. Surface isohalines for June, 1911.

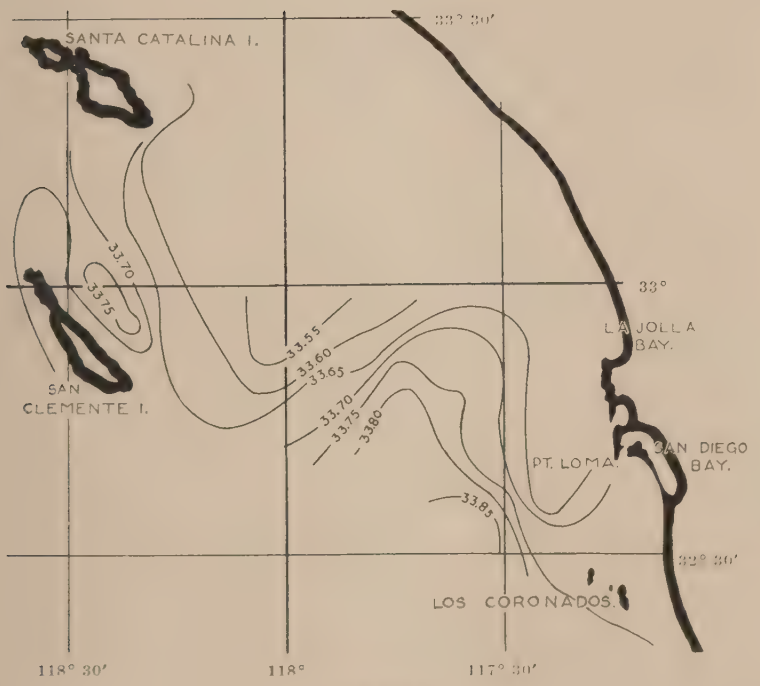

SANTA CATALINA I.
33° 30′
33°
LA JOLLA BAY.
SAN CLEMENTE I.
33.70
33.75
33.55
33.60
33.65
33.70
33.75
33.80
PT. LOMA.
SAN DIEGO BAY.
33.83
32° 30′
LOS CORONADOS.
118° 30′
118°
117° 30′

Fig. 13

PLATE 12

Fig. 14. Surface isohalines for July, 1909.

Fig. 15. Surface isohalines for February, 1909.

Fig. 16. Surface isohalines for September, 1909.

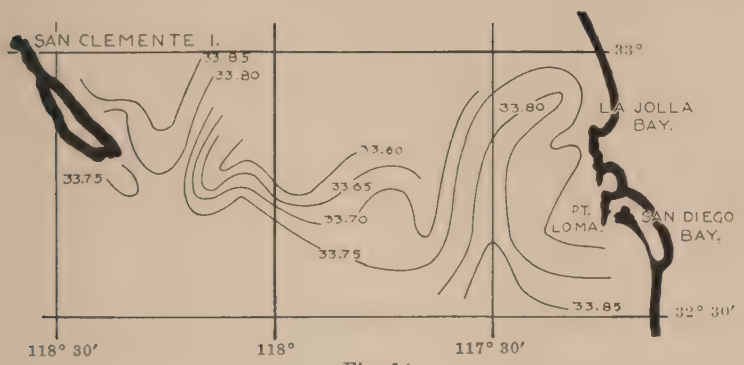


Fig. 14

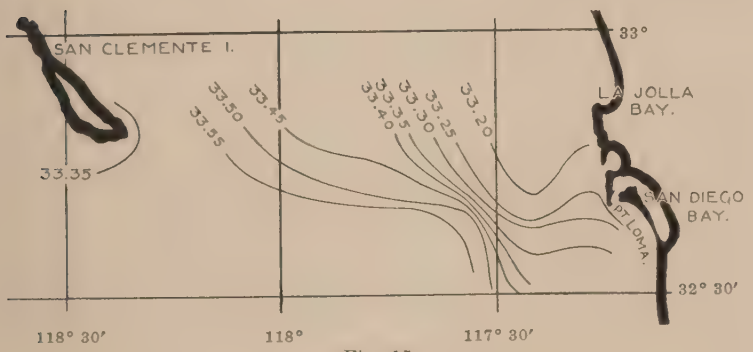


Fig. 15

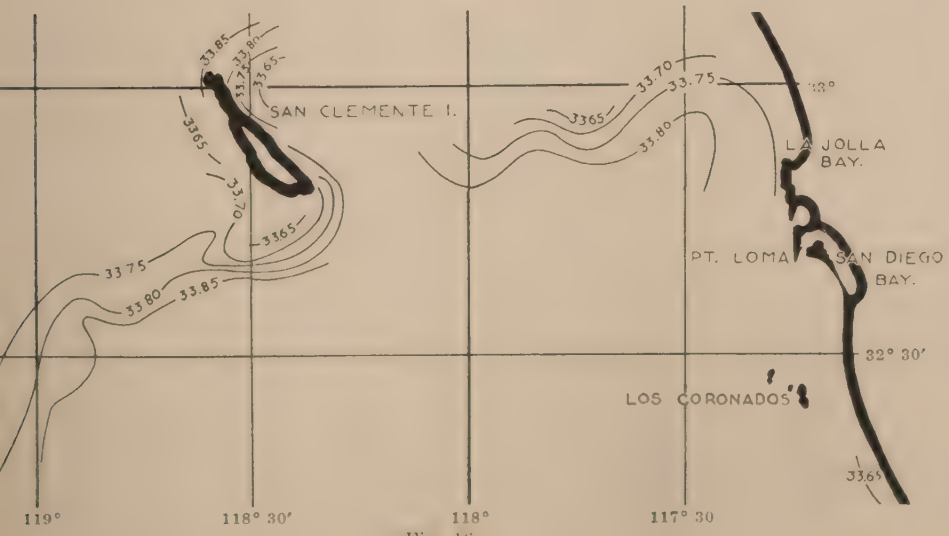


Fig. 16

PLATE 13

Fig. 17. Surface isohalines for July, 1908.

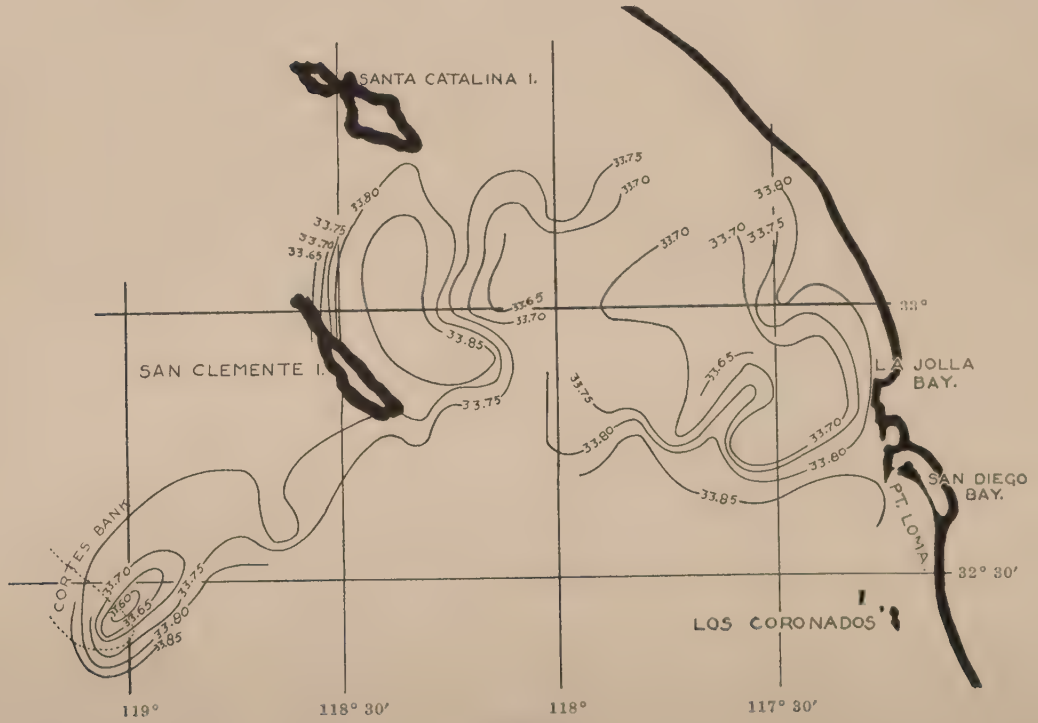

SANTA CATALINA I.
SAN CLEMENTE I.
LA JOLLA BAY.
SAN DIEGO BAY.
PT. LOMA
LOS CORONADOS
CORTES BANK
33°
32° 30′
119°
118° 30′
118°
117° 30′
33.80
33.75
33.70
33.65
33.85
33.60

Fig. 17

PLATE 14

Fig. 18. Surface isotherms for June, 1908.
Fig. 19. Surface isohalines for June, 1908.

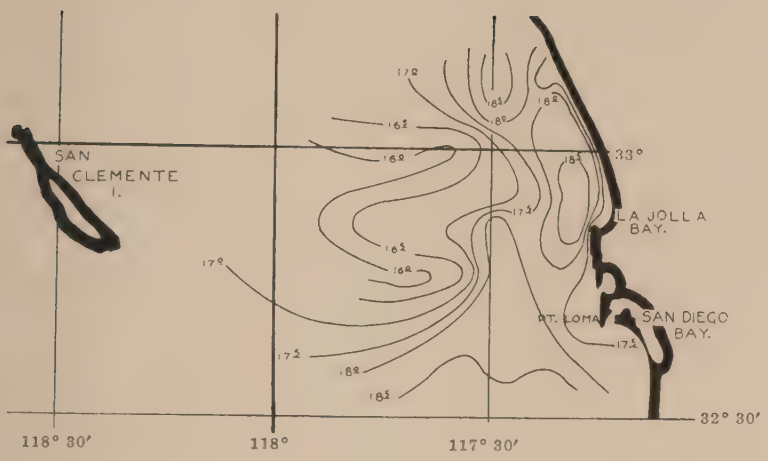

SAN CLEMENTE I.
LA JOLLA BAY.
SAN DIEGO BAY.
PT. LOMA
33°
32° 30′
118° 30′
118°
117° 30′

Fig. 18

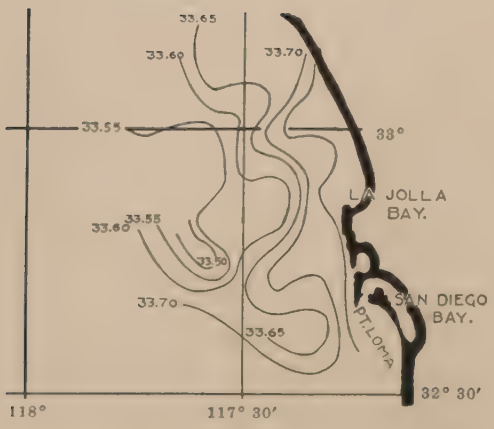

33.65
33.60
33.70
33.55
33°
LA JOLLA BAY.
33.60
33.55
33.50
33.70
33.65
SAN DIEGO BAY.
PT. LOMA
32° 30′
118°
117° 30′

Fig. 19

PLATE 15

Fig. 20. Surface isotherms of the Coronado Island region for June, 1911.

Fig. 21. Isotherms at depth 9 meters, in the Coronado Island region for June, 1911.

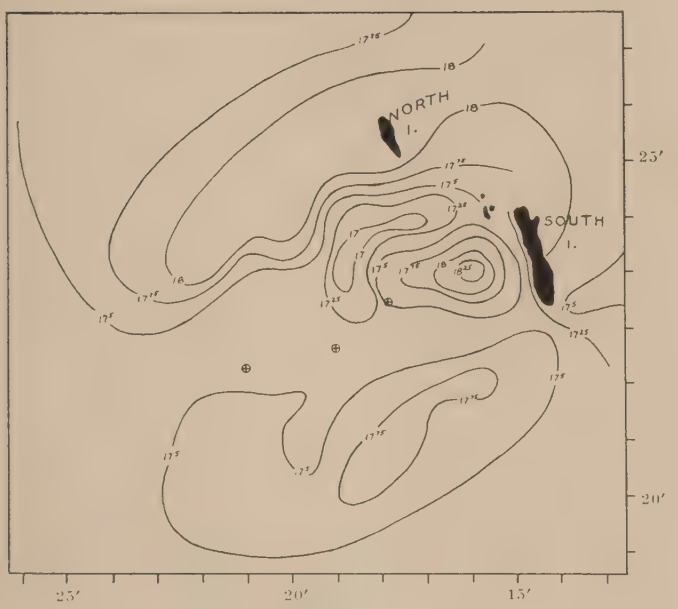


Fig. 20

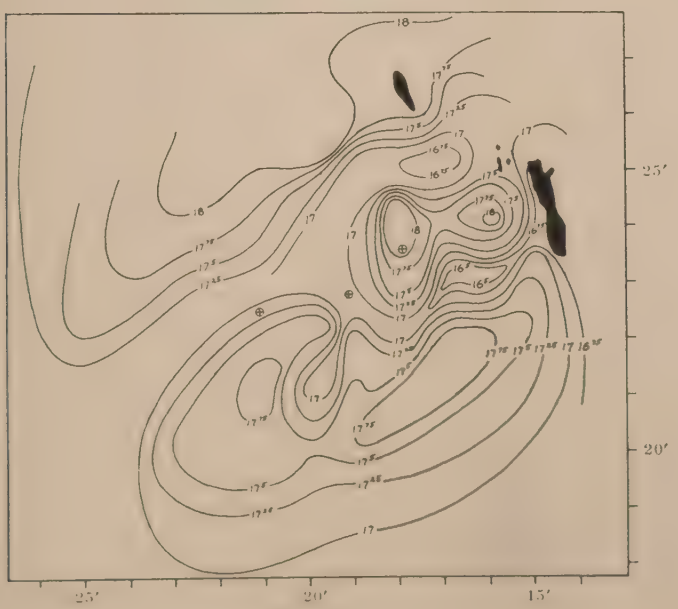


Fig. 21

PLATE 16

Fig. 22. Isotherms at depth 18 meters, in the Coronado Island region for June, 1911.

Fig. 23. Isotherms at depth 27 meters, in the Coronado Island region, for June, 1911.

Land at the level of the observations is indicated by diagonal cross-hatching in plates 16, 17, 18, 21, and 22.

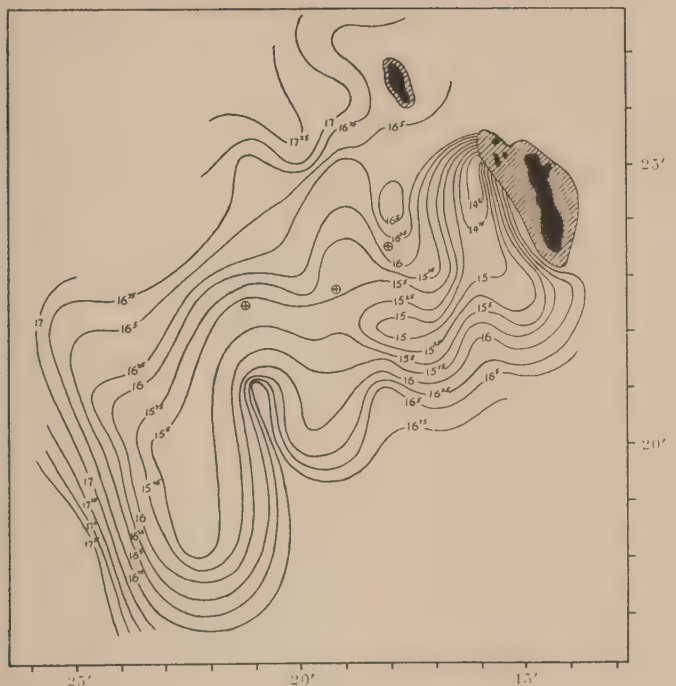


Fig. 22

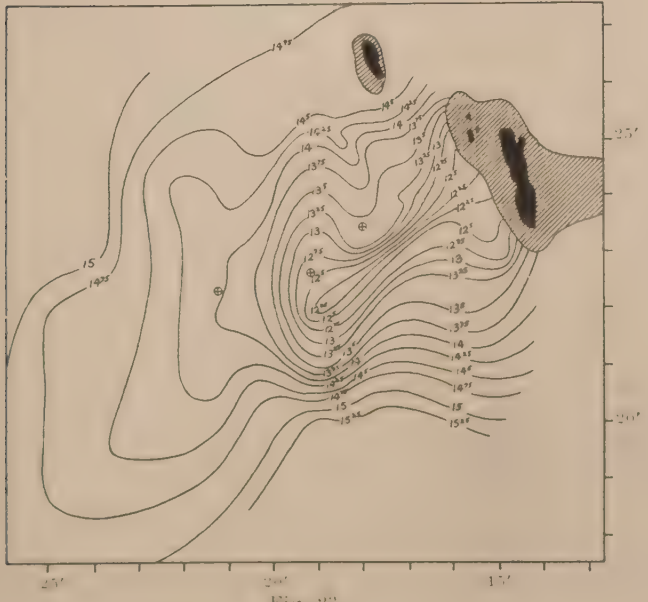


Fig. 23

PLATE 17

Fig. 24. Isotherms at depth 37 meters, in the Coronado Island region for June, 1911.

Fig. 25. Isotherms at depth 55 meters, in the Coronado Island region for June, 1911.

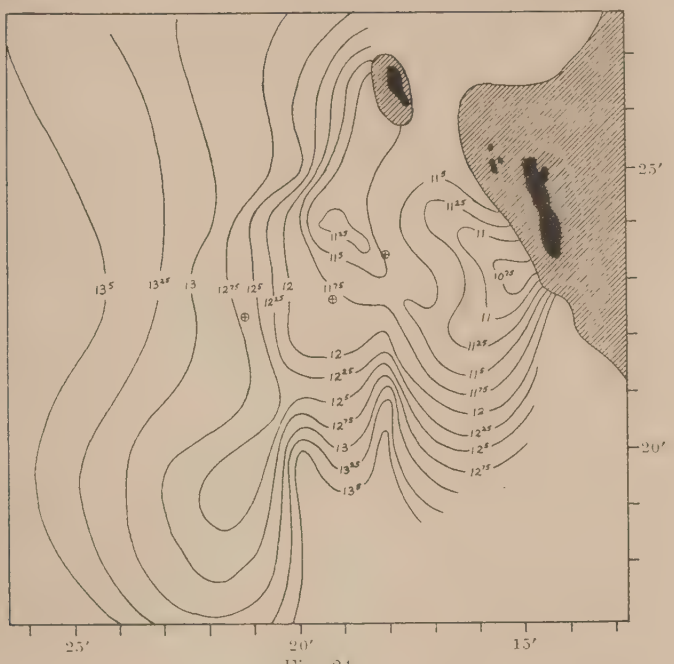

25′
20′
15′
13.5
13.25
13
12.75
12.5
12
11.75
11.5
11.25
11
10.75
12.25
12.75
13.25
13.5

Fig. 24

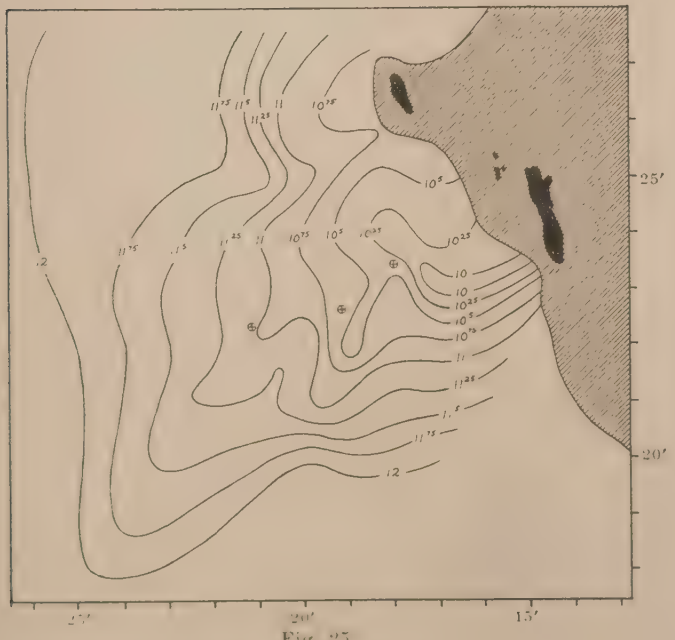

25′
20′
15′
11.75
11.5
11
10.75
10.5
10.25
10
11.25
11.5
11.75
12

Fig. 25

PLATE 18

Fig. 26. Isotherms at depth 64 meters, in the Coronado Island region for June, 1911.

Fig. 27. Isotherms at depth 92 meters, in the Coronado Island region for June, 1911.

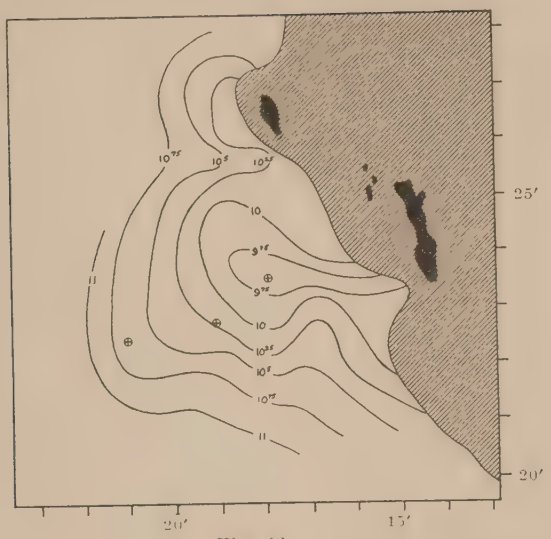


Fig. 26

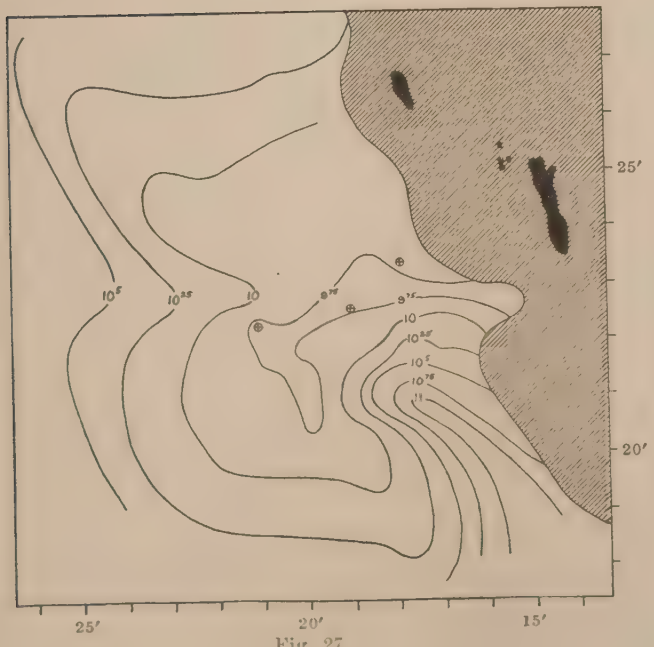


Fig. 27

PLATE 19

Fig. 28. Surface isotherms of the Coronado Island region for May, 1914.

Fig. 29. Surface isotherms of the Coronado Island region for July, 1912.

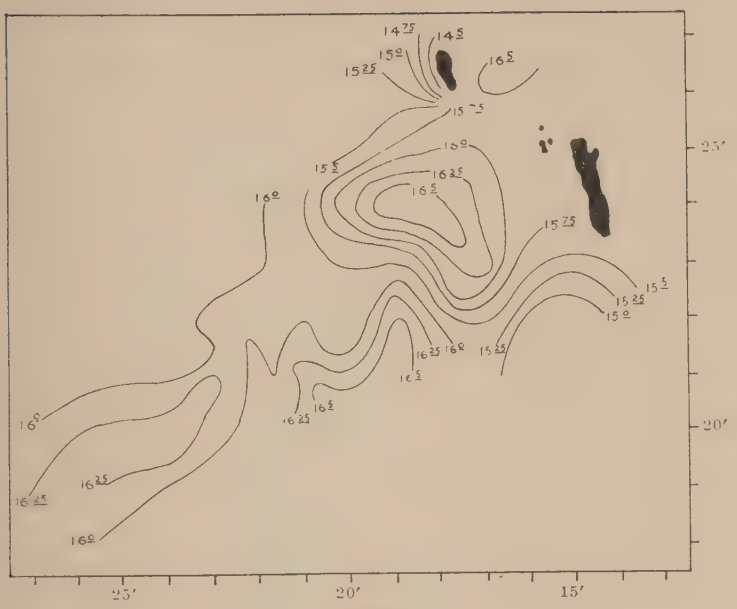


Fig. 28

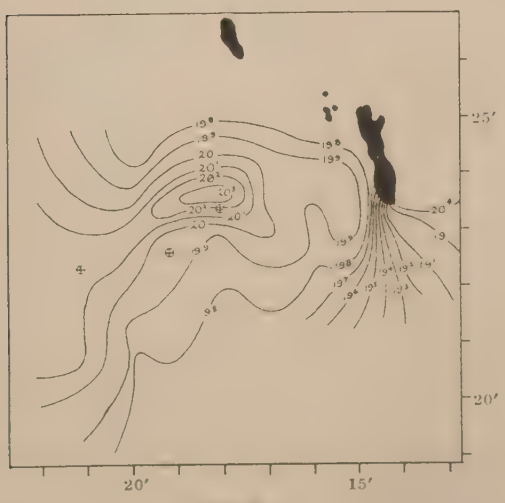


Fig. 29

PLATE 20

Fig. 30. Surface isohalines of the Coronado Island region for June, 1911.

NOTE.—The decimal part of the salinity is indicated for each isohaline in plates 20–22, but to save space the 33. is omitted.

Fig. 31. Isohalines at depth 9 meters, in the Coronado Island region for June, 1911.

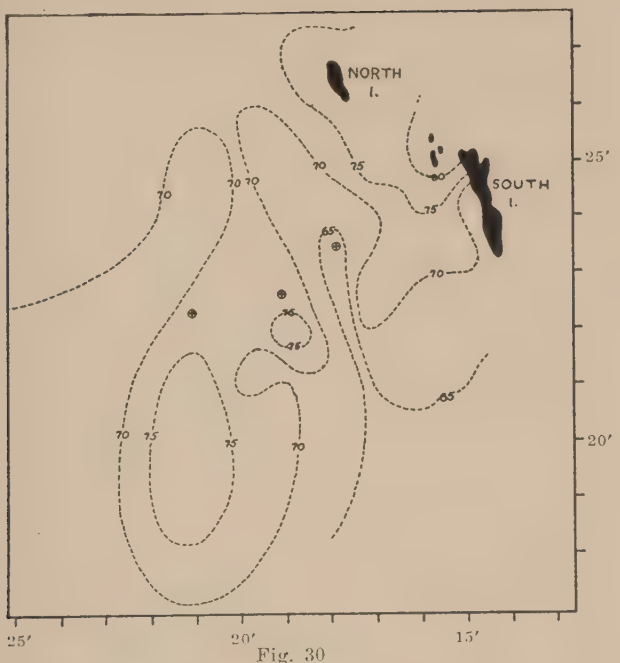


Fig. 30

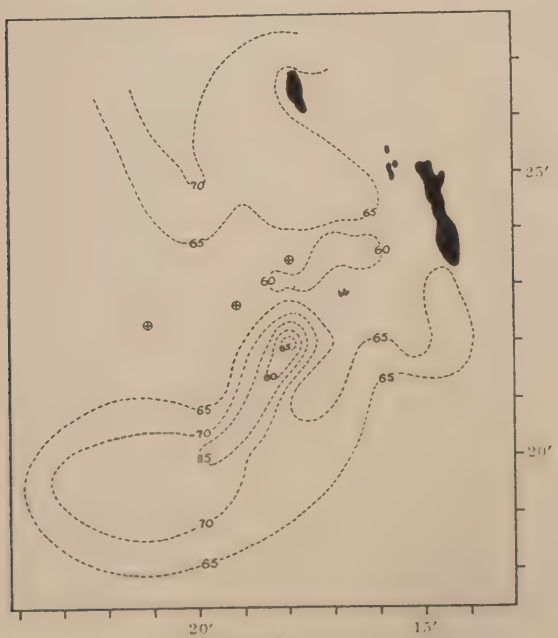


Fig. 31

PLATE 21

Fig. 32. Isohalines at depth 27 meters, in the Coronado Island region for June, 1911.

Fig. 33. Isohalines at depth 55 meters, in the Coronado Island region for June, 1911.

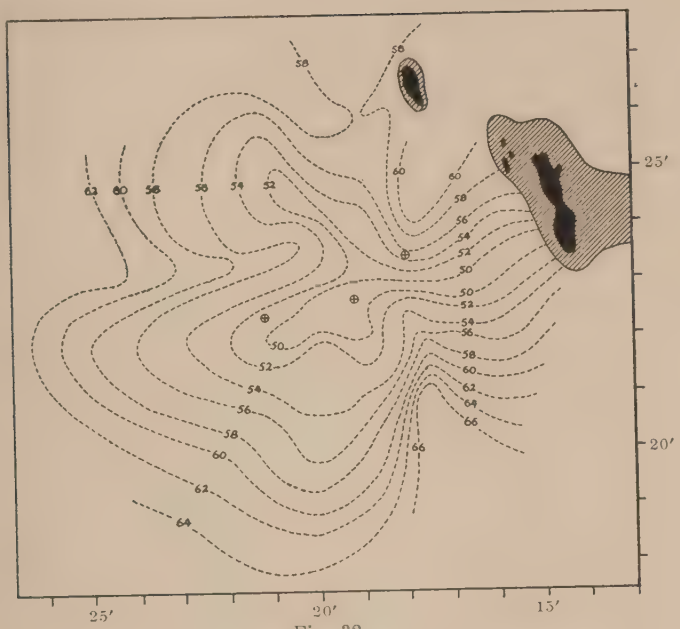


Fig. 32

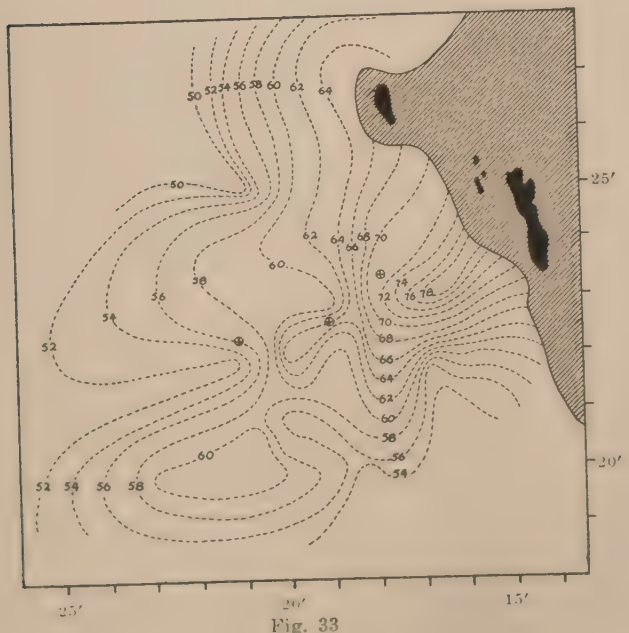


Fig. 33

PLATE 22

Fig. 34. Isohalines at depth 92 meters, in the Coronado Island region for June, 1911.

Fig. 35. Surface isohalines of the Coronado Island region for May, 1914.

25′
20′
20′
15′
66
68
70
72
74
76
78
80
82
84
74
76
78
80

Fig. 34

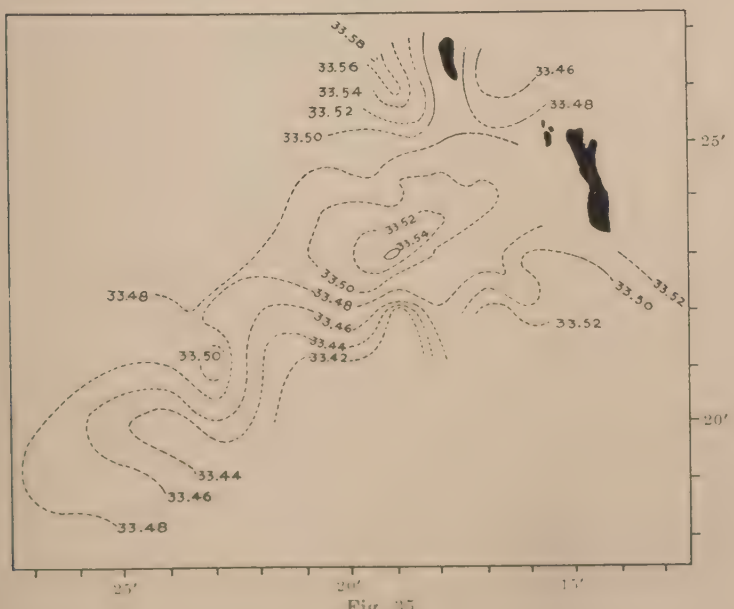

33.58
33.56
33.54
33.52
33.50
33.46
33.48
25′
20′
33.48
33.50
33.52
33.54
33.50
33.48
33.46
33.44
33.42
33.52
33.50
33.52
33.44
33.46
33.48
25′
20′

Fig. 35

PLATE 23

Fig. 36. Distribution of temperatures in a vertical plane perpendicular to the contours through Point Dume.

Fig. 37. Distribution of temperatures in a vertical plane perpendicular to the contours from a point three miles south of Point Loma.

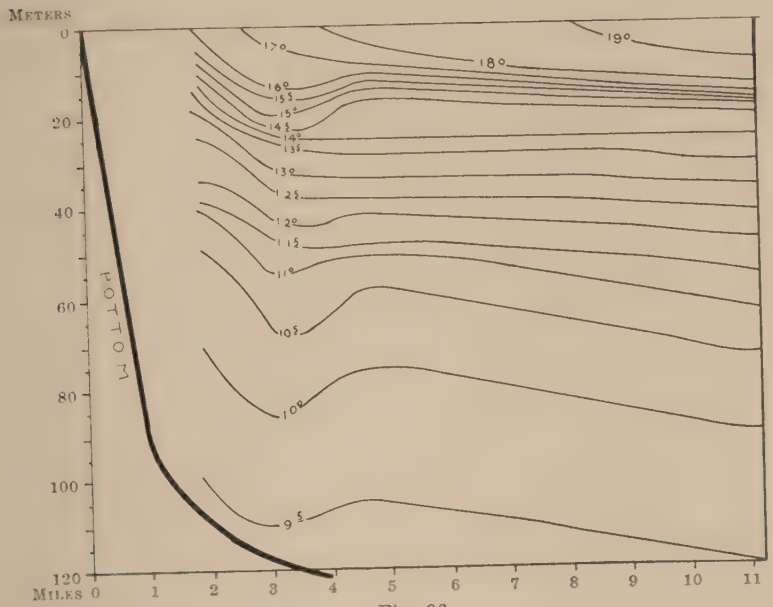

METERS
0
20
40
60
80
100
120
MILES 0 1 2 3 4 5 6 7 8 9 10 11
BOTTOM
19°
18°
17°
16°
15.5°
15°
14.5°
14°
13.5°
13°
12.5°
12°
11.5°
11°
10.5°
10°
9.5°

Fig. 36

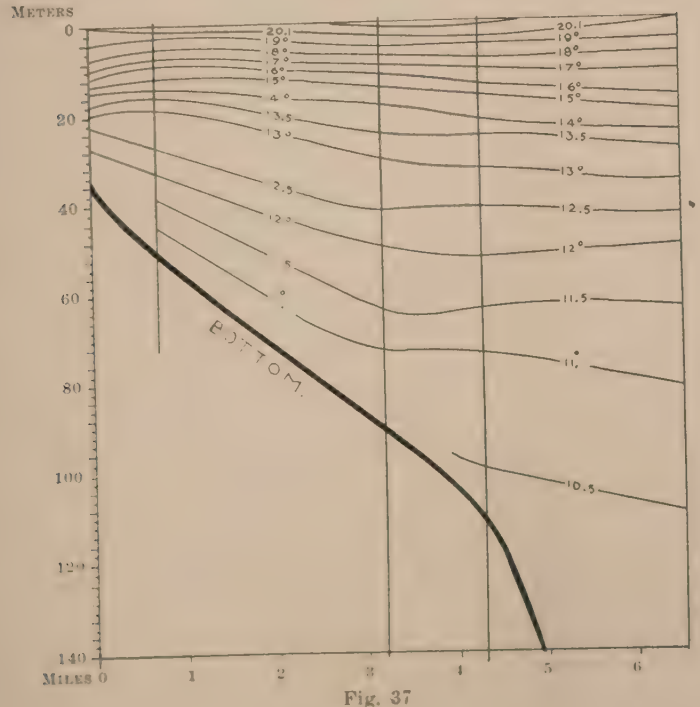

METERS
0
20
40
60
80
100
120
140
MILES 0 1 2 3 4 5 6
BOTTOM
20.1°
19°
18°
17°
16°
15°
14°
13.5°
13°
12.5°
12°
11.5°
11°
10.5°

Fig. 37

PLATE 24

Fig. 38. Distribution of salinity in a vertical plane perpendicular to the contours through Point Dume.

Fig. 39. Distribution of salinity in a vertical plane perpendicular to the contours through a point three miles south of Point Loma.

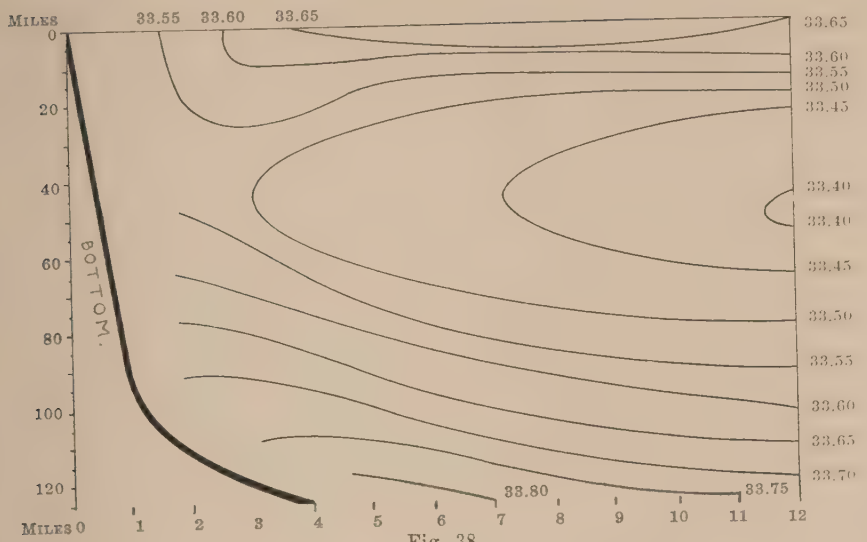

MILES
33.55
33.60
33.65
0
20
40
60
80
100
120
BOTTOM.
33.65
33.60
33.55
33.50
33.45
33.40
33.40
33.45
33.50
33.55
33.60
33.65
33.70
33.80
33.75
MILES 0 1 2 3 4 5 6 7 8 9 10 11 12

Fig. 38

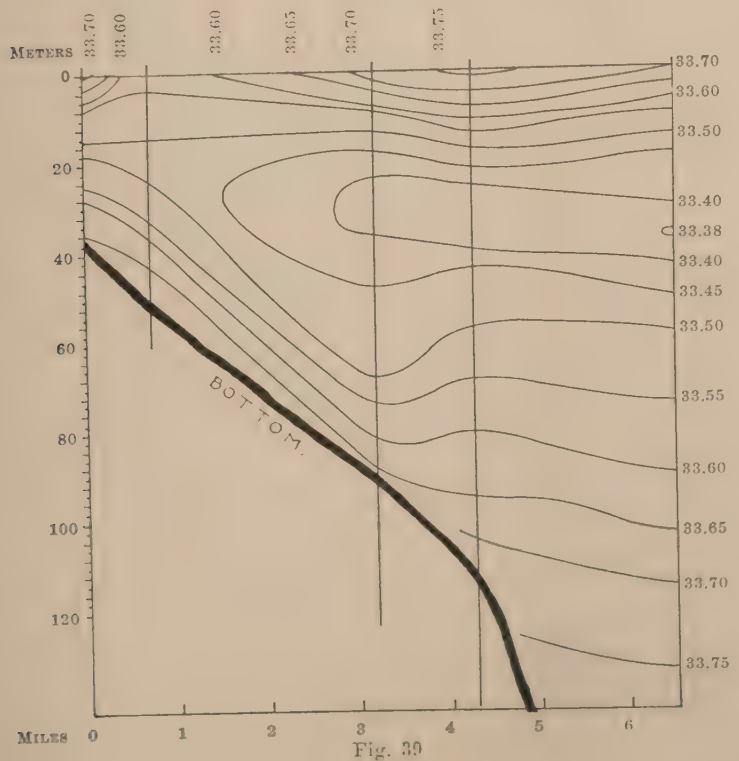

METERS
33.70
33.60
33.60
33.65
33.70
33.75
0
20
40
60
80
100
120
BOTTOM.
33.70
33.60
33.50
33.40
33.38
33.40
33.45
33.50
33.55
33.60
33.65
33.70
33.75
MILES 0 1 2 3 4 5 6

Fig. 39

PLATE 25

Fig. 40. Seasonal variation in surface temperatures based on observations made approximately eight miles west of South Coronado Island in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6.

Fig. 41. Seasonal variation in surface temperature based on observations made off Coronado Beach in section 38_8.

Fig. 42. Approximate average seasonal variation in the "normal" surface temperature of the North Pacific Ocean at 32° 30′ N.

Fig. 43. Seasonal variation in surface salinity, based on observations made approximately eight miles west of South Coronado Island in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6.

Fig. 44. Seasonal variation in surface salinity, based on observations made off Coronado Beach in section 38_8.

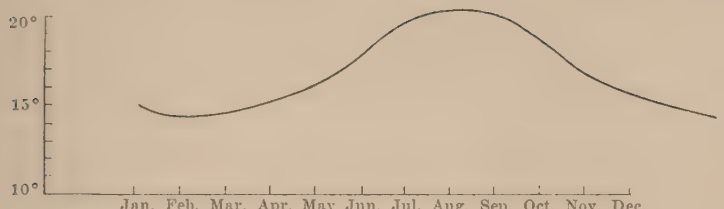


Fig. 40

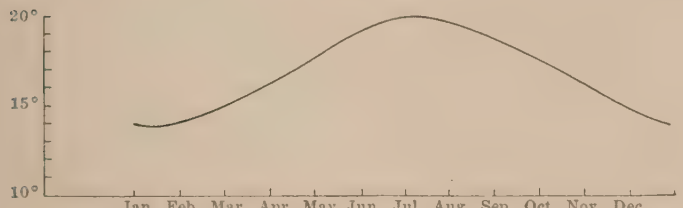


Fig. 41

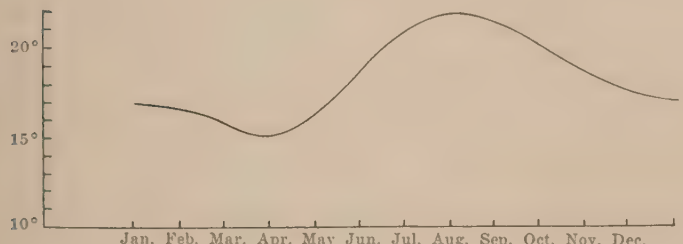


Fig. 42

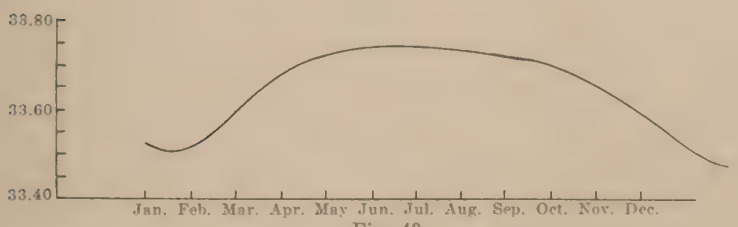


Fig. 43

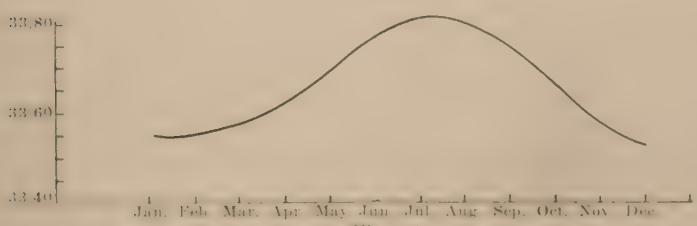


Fig. 44

PLATE 26

Fig. 45. Seasonal variation in temperature at all depths in a region approximately eight miles west of South Coronado Island in sections 40_4, 40_5, 40_6, 41_4, 41_5 and 41_6.

Fig. 46. Seasonal variation in salinity at all depths in a region approximately eight miles west of South Coronado Island in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6.

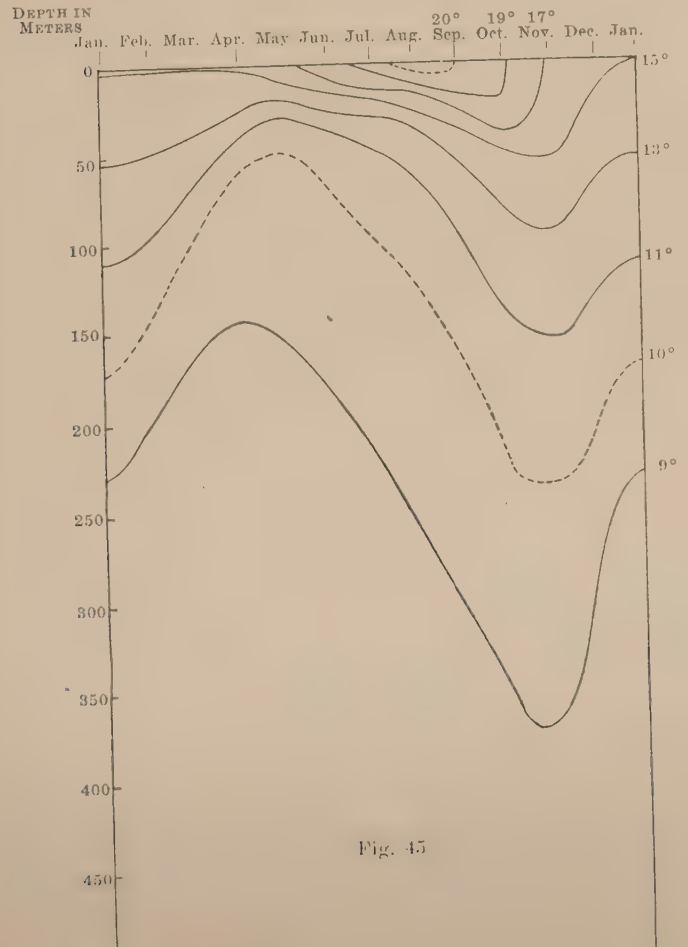

DEPTH IN METERS
Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec. Jan.
20° 19° 17°
0
50
100
150
200
250
300
350
400
450
15°
13°
11°
10°
9°

Fig. 45

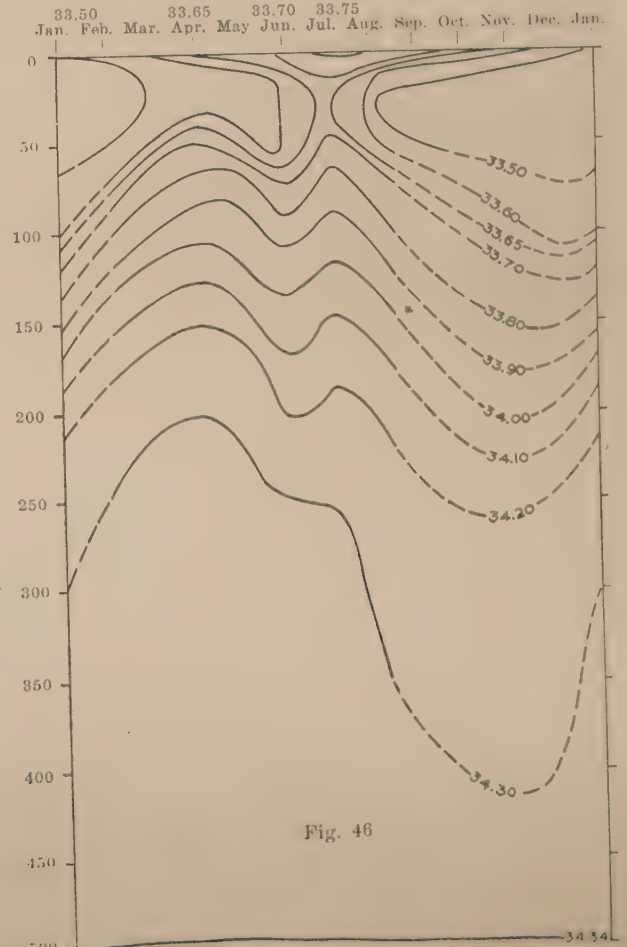

33.50 33.65 33.70 33.75
Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec. Jan.
0
50
100
150
200
250
300
350
400
450
33.50
33.60
33.65
33.70
33.80
33.90
34.00
34.10
34.20
34.30
34.34

Fig. 46

PLATE 27

Serial temperature curves corresponding to different months and based on observations made approximately eight miles west of South Coronado Island in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6.

NOTE.—The number of observations on which each curve is based is stated. But this number is an underestimate, since it does not include the observations made at the surface where so many more were made than at any other depth.

Fig. 47. Based on 28 observations; February, 1912.

Fig. 48. Based on 33 observations; February, 1913.

Fig. 49. Based on 62 observations; March, 1912.

Fig. 50. Based on 28 observations; April, 1912.

Fig. 51. Based on 69 observations; April, 1913.

Fig. 52. Based on 94 observations; May, 1914.

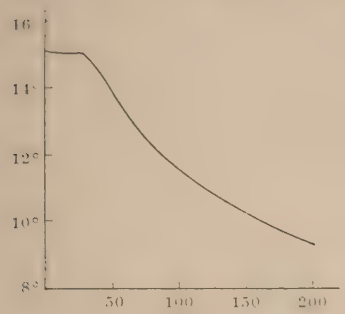


Fig. 47

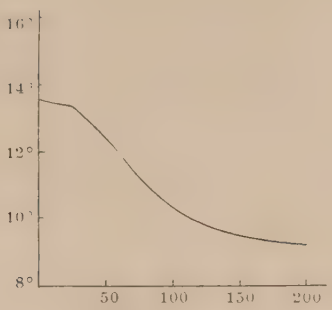


Fig. 48

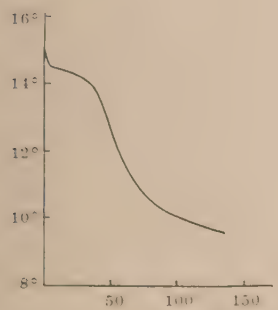


Fig. 49

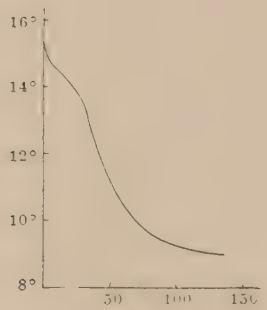


Fig. 50

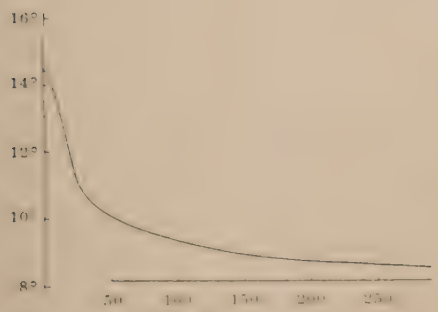


Fig. 51

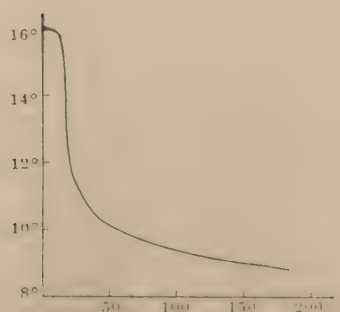


Fig. 52

PLATE 28

Serial temperature curves corresponding to different months and based on observations made approximately eight miles west of South Coronado Island in sections 40_4, 40_5, 40_6, 41_4, 41_5, 41_6 (see note under plate 27 relative to the number of observations).

Fig. 53. Based on 55 observations; May, 1915.

Fig. 54. Based on 380 observations; June, 1911.

Fig. 55. Based on 151 observations; July, 1912.

Fig. 56. Based on 56 observations; August, 1910.

Fig. 57. Based on 117 observations; August, 1911.

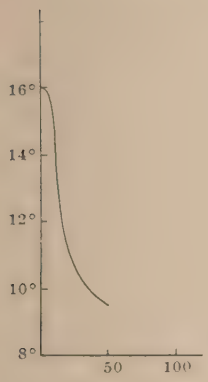


Fig. 53

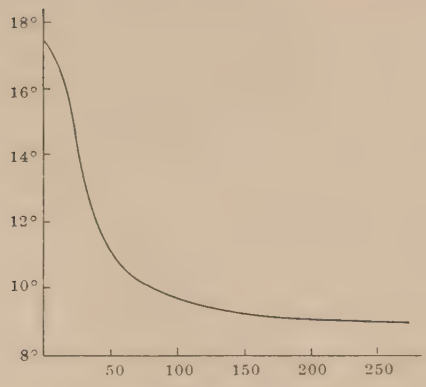


Fig. 54

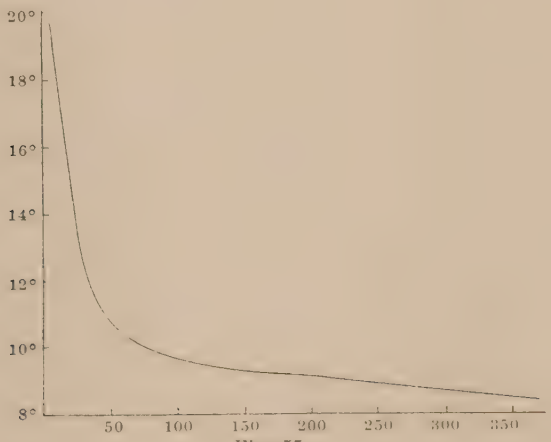


Fig. 55

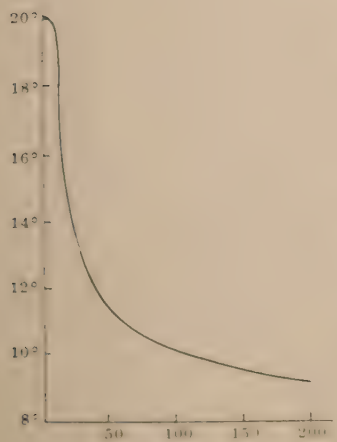


Fig. 56

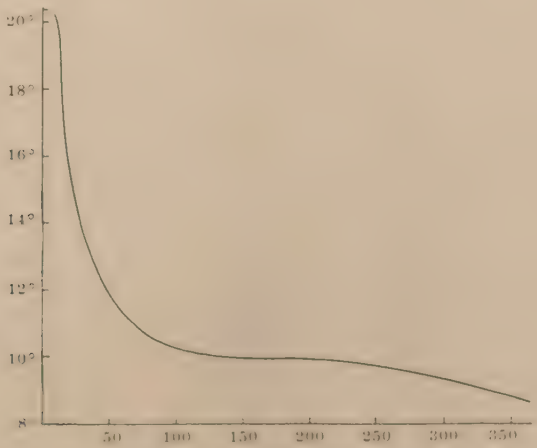


Fig. 57

PLATE 29

Serial temperature and salinity curves corresponding to different months and based on observations made approximately eight miles west of South Coronado Island in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6 (see note under plate 27 relative to the number of observations).

Temperature Curves

Fig. 58. Based on 30 observations; August, 1912.

Fig. 59. Based on 25 observations; October, 1911.

Salinity Curves

Fig. 60. Based on 33 observations; February, 1913.

Fig. 61. Based on 69 observations; April, 1913.

Fig. 62. Based on 94 observations; May, 1914.

Fig. 63. Based on 55 observations; May, 1915.

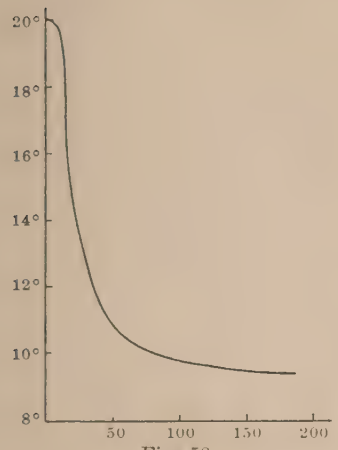


Fig. 58

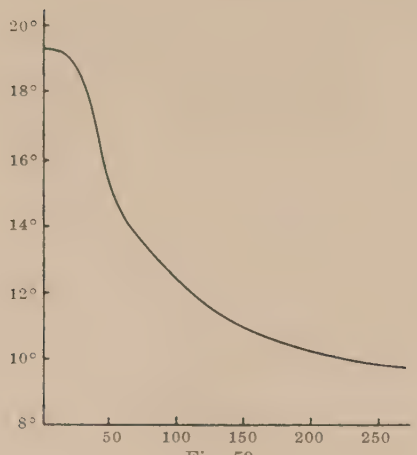


Fig. 59

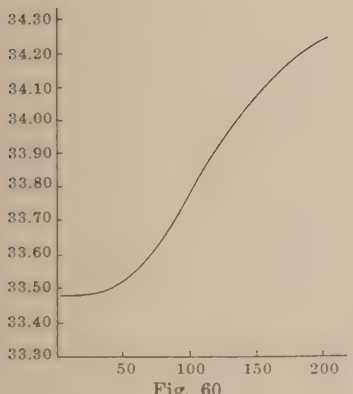


Fig. 60

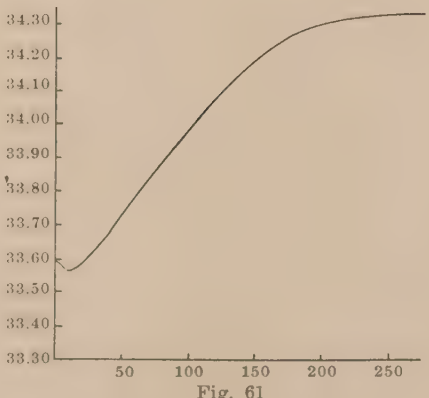


Fig. 61

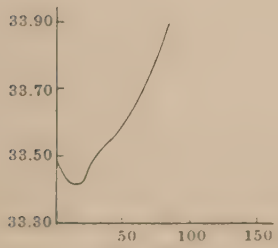


Fig. 62

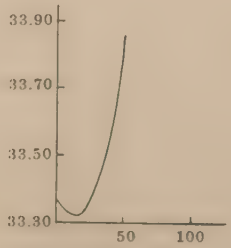


Fig. 63

PLATE 30

Serial salinity curves corresponding to different months and based on observations made approximately eight miles west of South Coronado Island in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6 (see note under plate 27 relative to the number of observations).

Fig. 64. Based on 380 observations; June, 1911.
Fig. 65. Based on 151 observations; July, 1912.
Fig. 66. Based on 56 observations; August, 1910.
Fig. 67. Based on 117 observations; August, 1911.
Fig. 68. Based on 30 observations; August, 1912.

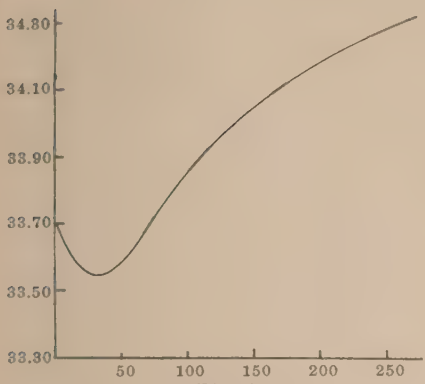


Fig. 64

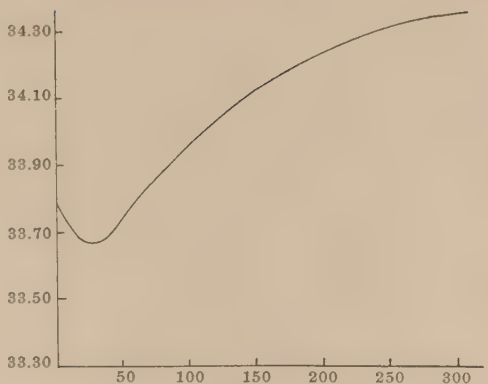


Fig. 65

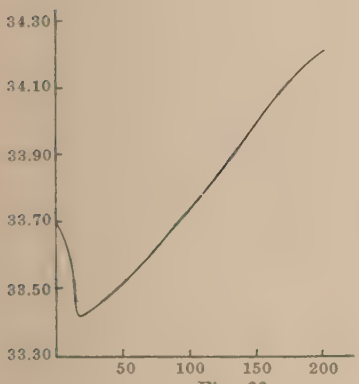


Fig. 66

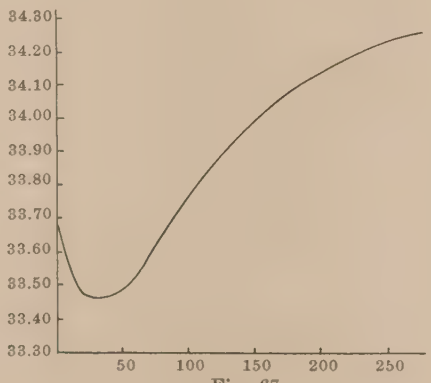


Fig. 67

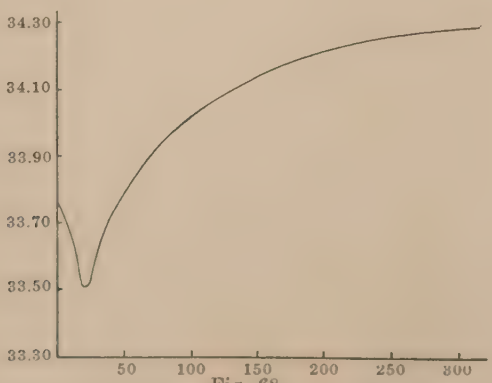


Fig. 68

PLATE 31

Serial temperature and salinity curves corresponding to different months (see note under plate 27 relative to the number of observations).

The curves in figures 69–72 are based on observations made approximately ten miles west of La Jolla in sections 40_9, 40_{10}, 40_{11}, 41_9, 41_{10}, 41_{11}, 42_9, 42_{10}, and 42_{11}.

Temperature Curves

Fig. 69. Based on 21 observations; June, 1911.

Fig. 70. Based on 22 observations; July, 1912.

Salinity Curves

Fig. 71. Based on 21 observations; June, 1911.

Fig. 72. Based on 22 observations; July, 1912.

The curves in figures 73–78 are based on observations made approximately three miles west of the Coronado Islands in sections 39_4 and 39_5.

Temperature Curves

Fig. 73. Based on 29 observations; February, 1913.

Fig. 75. Based on 130 observations; June, 1911.

Fig. 77. Based on 36 observations; August, 1911.

Salinity Curves

Fig. 74. Based on 29 observations; February, 1913.

Fig. 76. Based on 130 observations; June, 1911.

Fig. 78. Based on 36 observations; August, 1911.

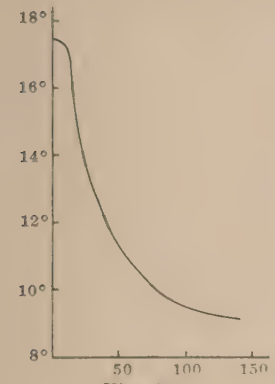


Fig. 69

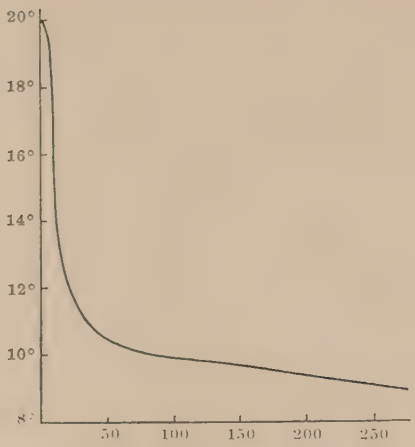


Fig. 70

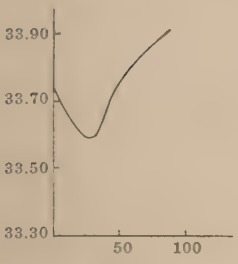


Fig. 71

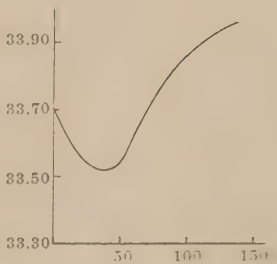


Fig. 72

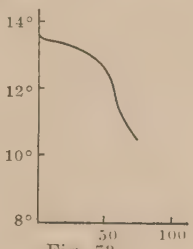


Fig. 73

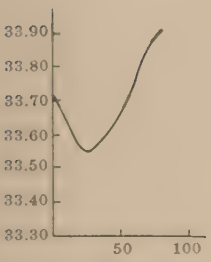


Fig. 76

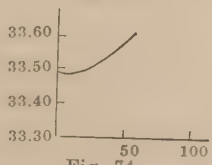


Fig. 74

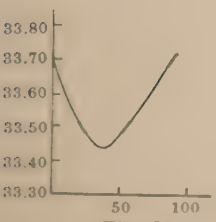


Fig. 78

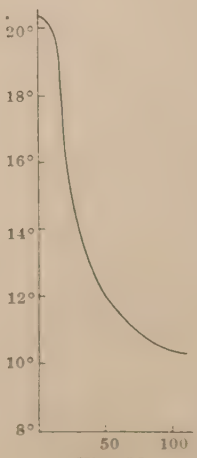


Fig. 77

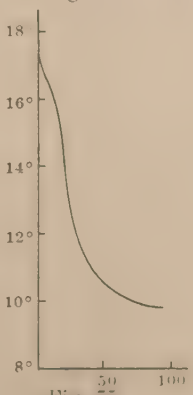


Fig. 75

PLATE 32

Serial temperature and salinity curves corresponding to different months (see note under plate 27 relative to the number of observations).

The curves in figures 79–84 are based on observations made off the west coast of South Coronado Island in section 39_5.

Temperature Curves

Fig. 79. Based on 8 observations; February, 1913.

Fig. 81. Based on 17 observations; June, 1911.

Fig. 83. Based on 11 observations; August, 1911.

Salinity Curves

Fig. 80. Based on 8 observations; February, 1913.

Fig. 82. Based on 17 observations; June, 1911.

Fig. 84. Based on 11 observations; August, 1911.

The curves in figures 85–90 are based on observations made in a region approximately three miles south of Point Loma in section 39_7.

Temperature Curves

Fig. 85. Based on 10 observations; February, 1913.

Fig. 87. Based on 10 observations; June, 1911.

Fig. 89. Based on 6 observations; August, 1911.

Salinity Curves

Fig. 86. Based on 10 observations; February, 1913.

Fig. 88. Based on 10 observations; June, 1911.

Fig. 90. Based on 6 observations; August, 1911.

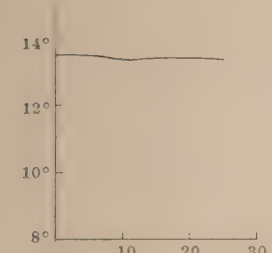


Fig. 79

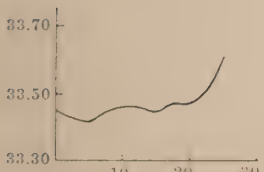


Fig. 80

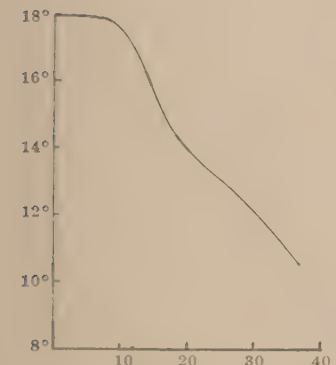


Fig. 81

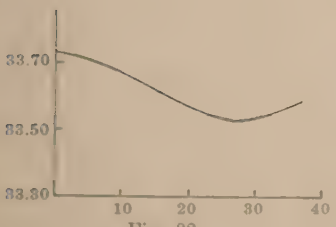


Fig. 82

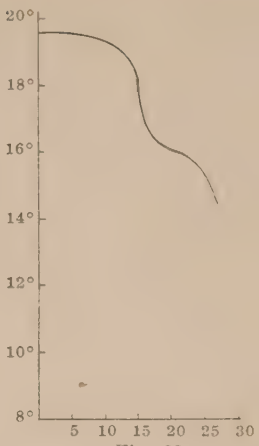


Fig. 83

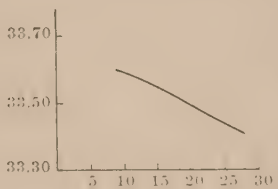


Fig. 84

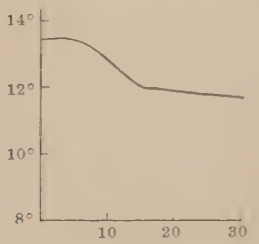


Fig. 85

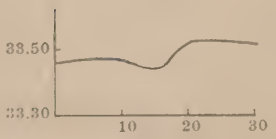


Fig. 86

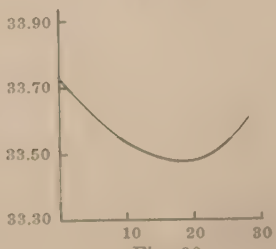
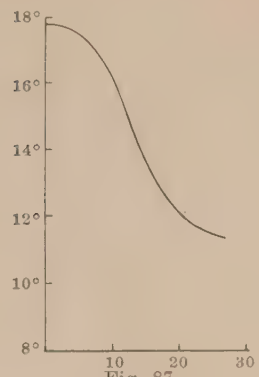


Fig. 90



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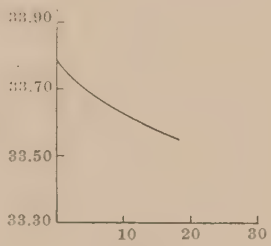

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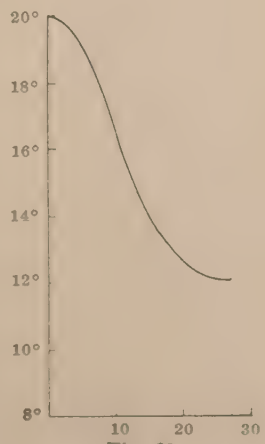


Fig. 89

PLATE 33

Seasonal variation in surface temperature and salinity of Glorietta Bight (a shallow inlet of the bay) and of San Diego Bay.

Fig. 91. Variation in surface salinity of Glorietta Bight.

Fig. 92. Variation in surface temperature of Glorietta Bight.

Fig. 93. Variation in the surface temperature of San Diego Bay.

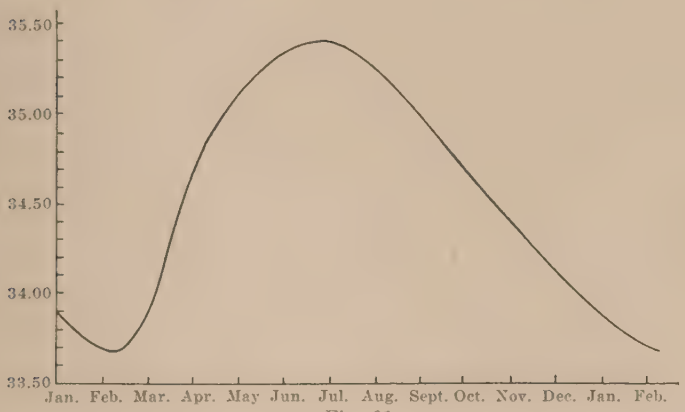


Fig. 91

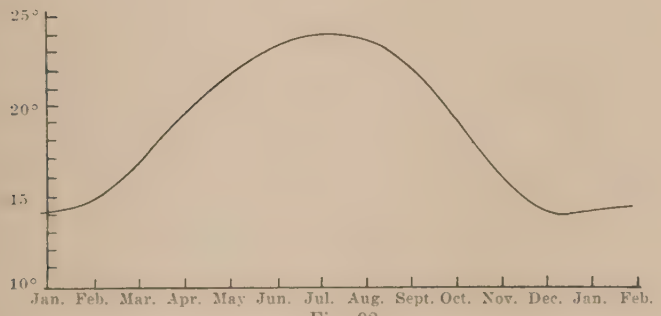


Fig. 92

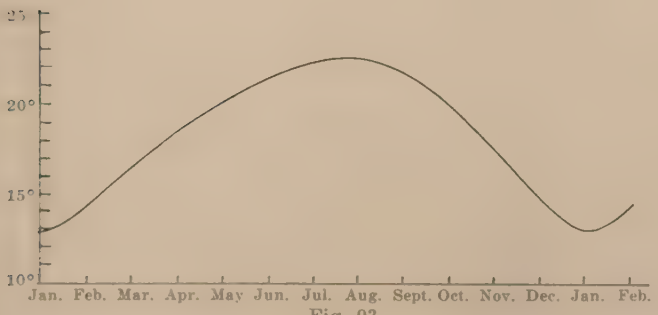
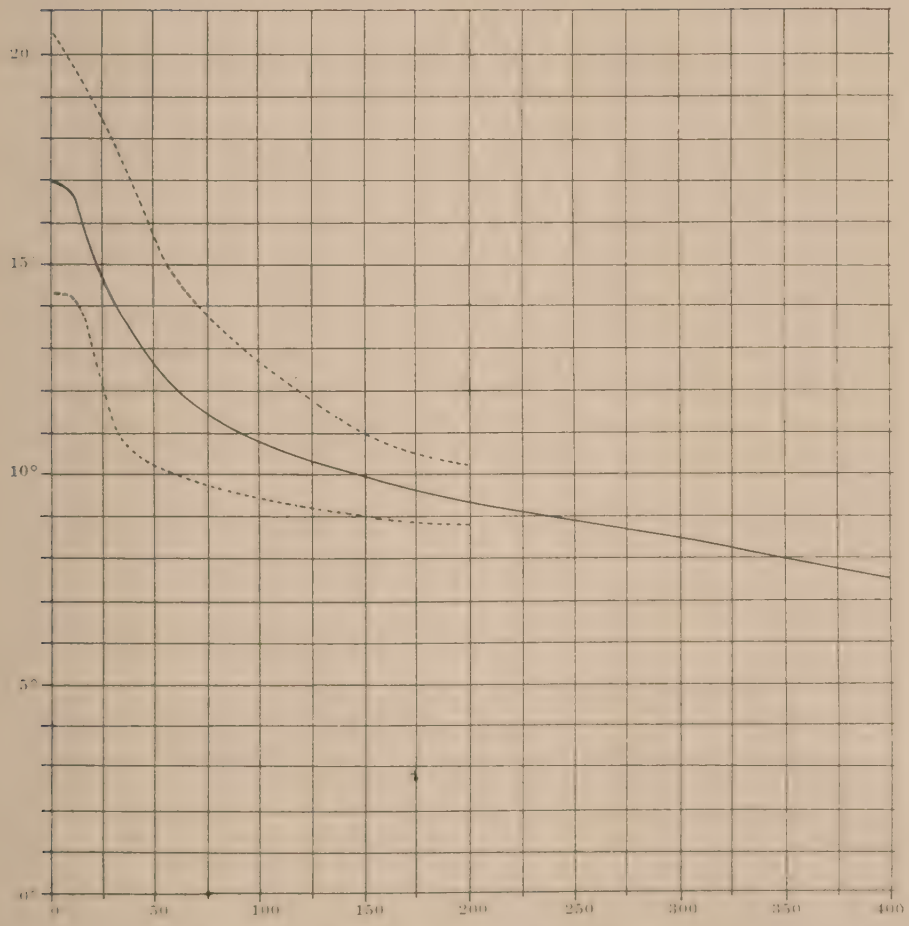


Fig. 93

PLATE 34

Fig. 94. Relation of mean annual temperature to depth and the maximum and minimum monthly average values at each depth, based on observations made in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6.



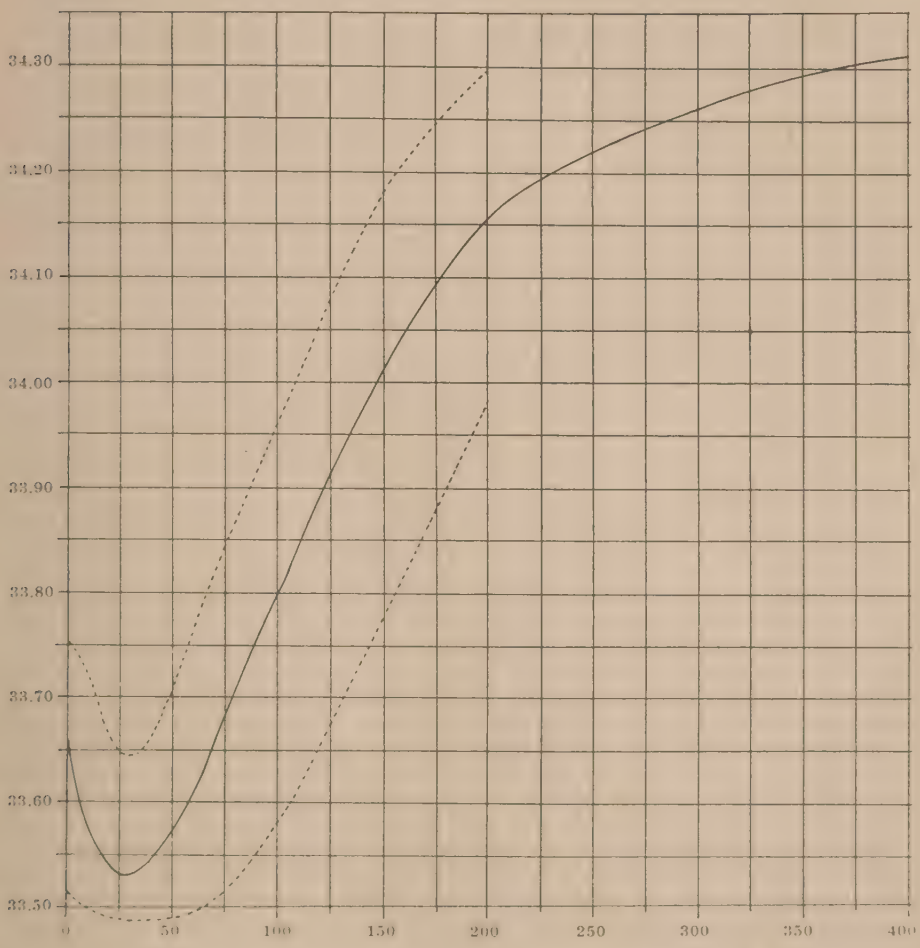
Curve showing relation of mean annual temperature to depth.

Curves showing maximum and minimum temperatures at all depths less than 200 meters.

Fig. 94

PLATE 35

Fig. 95. Relation of mean annual salinity to depth and the maximum and minimum monthly average values at each depth, based on observations made in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6.



——— Curve showing relation of mean annual salinity to depth.

..... Curves showing maximum and minimum salinities at all depths less than 200 meters.

Fig. 95

PLATE 36

Fig. 96. Average relation of temperature to depth from four to fourteen hundred meters.

Fig. 97. Average relation of salinity to depth from four to fourteen hundred meters.

Fig. 98. Relation of temperature to depth in sections 40_4, 40_5, 40_6, 41_4, 41_5, and 41_6 corresponding to February and August.

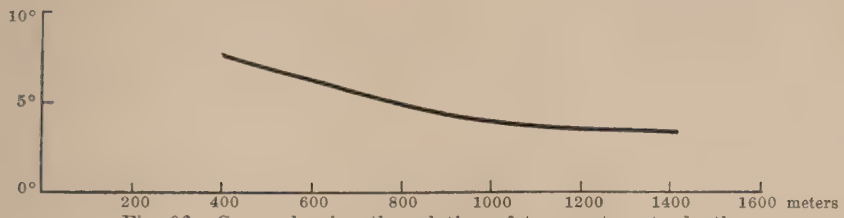


Fig. 96. Curve showing the relation of temperature to depth at depths exceeding 400 meters.

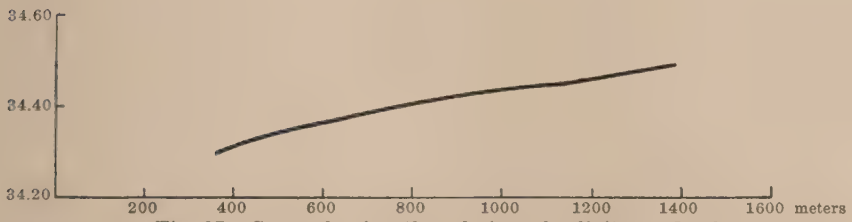


Fig. 97. Curve showing the relation of salinity to depth at depths exceeding 400 meters.

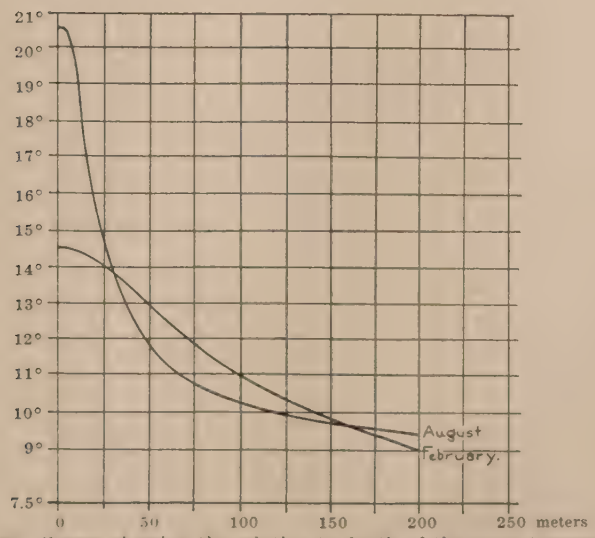


Fig. 98. Curves showing the relation to depth of the mean temperature for the months of February and August.

PLATE 37

Fig. 99. Relation of salinity to depth in sections 40_4, 40_5, 40_6, 41_4, 41_5 and 41_6 corresponding to February and August.

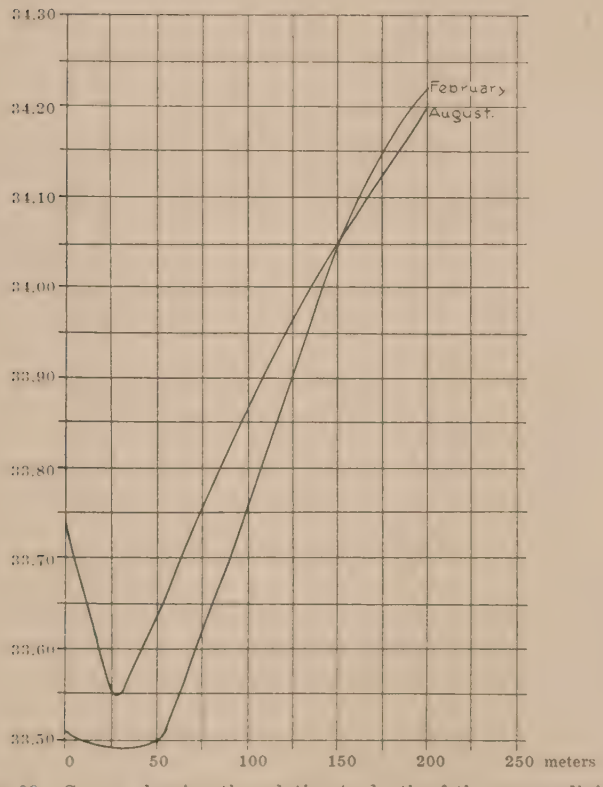


Fig. 99. Curves showing the relation to depth of the mean salinity for the months of February and August.

PLATE 38

Fig. 100. Theoretical average distribution of light intensity with respect to depth and time of day. The number on each curve denotes the intensity, assuming it to be one thousand (1000) at the depth of one meter.

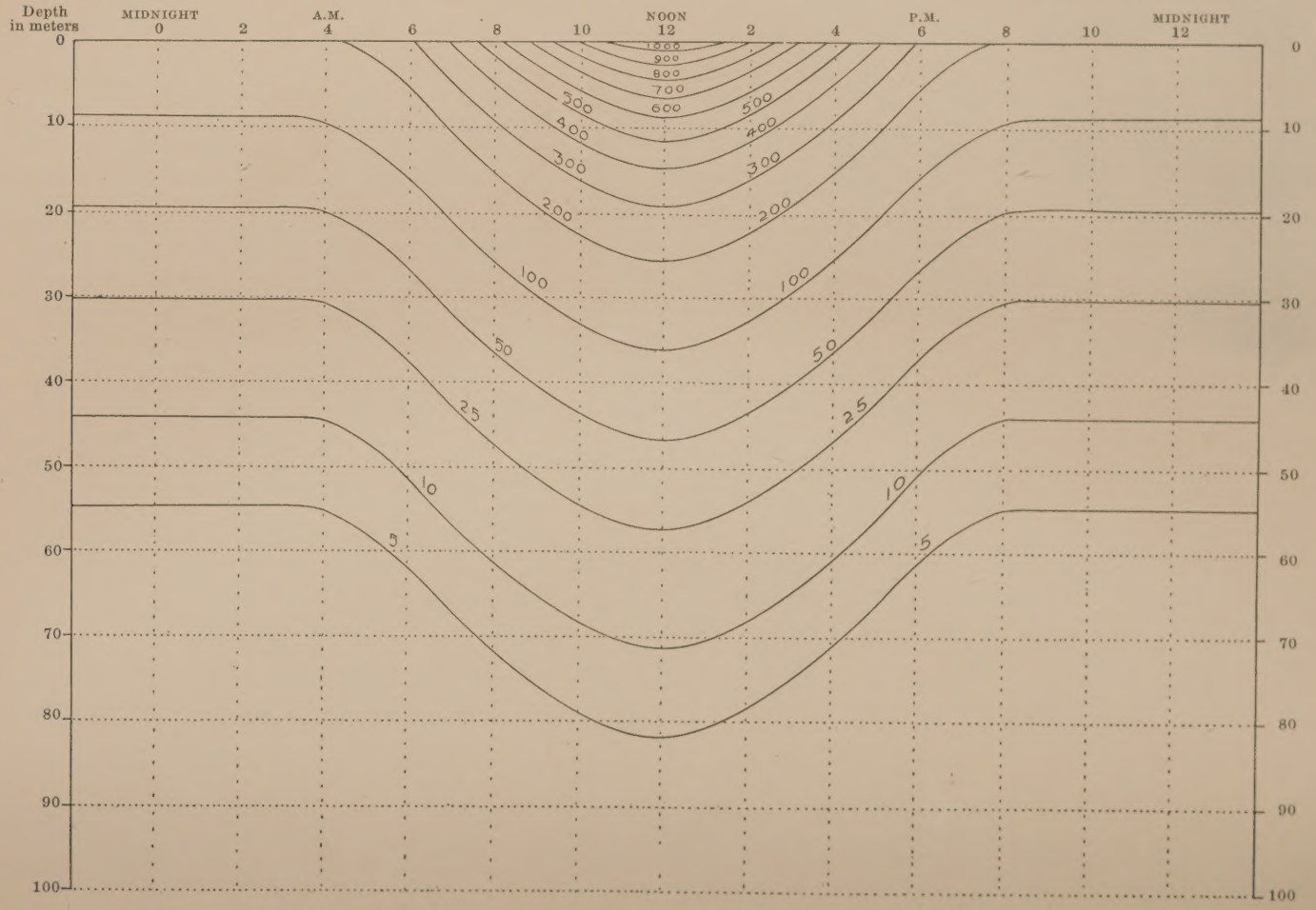


Fig. 100. The distribution of light intensity with respect to depth and time of day.

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Nos. 6 and 7 in one cover. December, 1915 ..... .25

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